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# WPI Stormwater Management Plan

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# WPI Stormwater Management Plan and Design of Permeable Pavements for Runoff Reduction

A Major Qualifying Project
in partial fulfillment of the requirements for the
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# Abstract

It is recognized that there is a need for effective approaches to mitigate the impacts of stormwater runoff on surface water bodies. Creating a stormwater management plan and designing best management practices can reduce the impacts of this runoff. For this project, a stormwater management plan was developed for Worcester Polytechnic Institute (WPI). The plan includes public education, detection of illicit discharges, construction and post construction site controls, and pollution prevention and best management practices (BMPs). After mapping the area with GIS and completing runoff calculations, a permeable pavement design was created and recommended as a BMP to reduce stormwater runoff from WPI. The design would significantly reduce the stormwater runoff discharge from the campus.

## Capstone Design Statement

The Accreditation Board for Engineering and Technology (ABET) states that "Students must be prepared for engineering practice through curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability; manufacturability; ethical; health and safety; social; and political." Our team created a stormwater management plan for WPI with the design of permeable pavement installation. The stormwater management plan included public outreach, illicit discharge detection and elimination, construction and post-construction site runoff controls, and future pollution prevention. The permeable pavement design includes a test plot and full pavement design for the Boynton Street Parking Lot. Through this design we met the ABET criterion as follows:

- Economic: For this design, the permeable pavement installation could have been in various locations on campus. The decision to install in the Library Lot took into the cost benefit, specifically looking into initial cost, annual cost, and investment return.
- Environmental: The goal of this project was to decrease the stormwater runoff that enters Salisbury Pond from WPI. By decreasing runoff, the pond will have lower inflow and fewer pollutants, which will increase the water quality of the pond.

- Sustainability: When designing this project, longevity of the pavements was one of the biggest aspects focused on. The permeable pavement design was chosen because of the positive impact on Salisbury, as well as the life span of about 20 years. Also included in the Stormwater management plan is a five-year plan which aims to improve sustainability.
- Health and Safety: The EPA classifies Salisbury Pond as a having rapid sedimentation and excessive bacterial loads. The pond is designed as a habitat for aquatic life and wildlife, and for primary and secondary contact recreation. The permeable pavement design strives to reduce contamination and runoff that could cause potential harm to humans and aquatic life.

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# Authorship

Two Environmental Engineering students, Amanda Houyou and Robert Medaglio, completed this project. Efforts were divided as follows: Robert Medaglio provided the GIS analysis and type III rainfall graph. Equivalent efforts were put into analyzing the data. Amanda Houyou wrote the final report.

Acknowledgments

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- Dr. Paul P. Mathisen for serving as advisor and mentor to us throughout the course of this research. His insight, patience, and support were instrumental in the completion of this work.

# 1.0 Introduction

The Environmental Protection Agency (EPA) states that, “stormwater runoff from construction activities and sewers in large urban areas significantly impairs water quality in rivers, lakes, streams, reservoirs, estuaries, near-shore ocean, and wetlands nation-wide” (EPA, 2012). Stormwater runoff causes issues because it collects debris, chemicals, dirt, and other pollutants and then runs into water bodies. When sediments enter the water bodies, the water turns cloudy and in effect, aquatic plants have difficulty growing. Bacteria, pathogens, and household hazardous wastes that enter the water bodies from runoff can create health hazards for aquatic life or public use. Some common household hazardous wastes that end up in runoff are insecticides, pesticides, paint, solvents, motor oil and other auto fluids. In addition, debris that collects and enters the water often chokes, suffocates, and disables aquatic life. Stormwater runoff pollutants can be monitored and decreased with close attention (EPA, 2003).

The EPA has established a number of programs intended to address concerns with the quantity and quality of stormwater in the United States. For example, the EPA has a Pretreatment Program that regulates and restricts discharge of stormwater (EPA, 2008). The National Pollutant Discharge Elimination Systems (NPDES) program was developed to help protect and restore the quality of the rivers, lakes, and coastal waters (EPA, 2014). Under NPDES, the EPA is authorized to set effluent limits on an industry-wide basis and on a water-quality basis that ensures protection of the receiving water. As a result, many communities and organizations are considering the development of stormwater management plans to help control stormwater runoff.

Worcester Polytechnic Institute (WPI) is located at the top of a steep hill and stormwater runs off in all directions. As seen in the GIS map of WPI campus in Figure 1, stormwater runoff from WPI enters Salisbury Pond through the inlet highlighted in red. This pond was categorized as having high having Nuisance Aquatic Plants and turbidity associated with high phosphorous loadings. Although WPI is not the main contributor to the pollutant levels in the pond it is important for the campus to put in place a plan to prevent high volume runoff.


**Figure 1: GIS Map of Campus**

Over the past few years, WPI has made great strides in improving its sustainability on campus. WPI's campus sustainability plan's vision states "WPI will demonstrate a commitment to improving the quality of life for current and future generations. "[WPI] will accomplish this goal by promoting a culture of sustainability that incorporates the beliefs and behaviors supported by our technical strengths and by our heritage of the application of both theory and practice, as embodied in our motto Lehr and Kunst, to the solution of important problems." (Tomaszewski, 2013). Many college campuses are creating stormwater management plans intended to reduce runoff and increase sustainability. Currently Worcester Polytechnic Institute does not have a stormwater management plan set in place. As the campus continues to improve sustainability, it will be increasingly beneficial for a plan to be set in place. A stormwater management plan for WPI fits into the goals of the campus to increase sustainability. A stormwater management plan can decrease the volume runoff entering the pond as well as pollutant concentration.

The goal of this project is to create a WPI Stormwater Management Plan that will increase awareness, reduce stormwater runoff, and reduce pollutant concentrations entering Salisbury Pond. Included in the Stormwater Management plan is public education, detection of illicit discharges, construction and post construction site controls, and pollution prevention and best management practices.

To meet the goals of developing a stormwater management plan with an approach to reduce stormwater flows and loads discharging from the WPI campus, the project included:

- Analysis of facility records to gather statistics on current stormwater data
- Creation of a GIS map of WPI campus that tracks runoff and analyzes pervious surfaces
- Completion of flow and load calculations to quantify runoff for the campus
- Determination of priority areas on campus for installation of best management practices

After completing these steps, the design alternative of the installation of permeable pavement at the Boynton Street Parking lot was proposed as a best management practice.

To display the information needed for this project, the report is broken down into five chapters. Chapter one includes an introduction and scope of the project Chapter two includes a background of Massachusetts and City of Worcester permitting regulations, information on Salisbury Pond, reviews of four university stormwater management plans, and an overview of best management practices for stormwater management. Chapter three reviews the steps taken to meet the goals of the project including: GIS mapping of campus to track runoff, flow and load calculations to quantify runoff of the different areas, and Identification of priority areas. Chapter four outlines the proposed Stormwater

Management Plan for WPI with main sections being: public education, detection of illicit discharge, construction and post construction site controls, and pollution prevention and best management practices. Chapter five covers all results drawn form the research of this project and the design option of permeable pavement recommended as a best management practice. Chapter six summarizes the conclusions and provides recommendations.

# 2.0 Background

Stormwater management plans are becoming increasingly more popular for institutions across the United States. An effective management plan can provide approaches to mitigate pollutant content, and decrease runoff volume entering waterbodies. This chapter provides an overview of the background research to support the development of a stormwater management plan at WPI. Topics include other university stormwater management plans, Massachusetts permitting, and stormwater plans for the City of Worcester. Since there is an interest in reducing flows and loads to Salisbury Pond, this chapter also includes information on the water quality concerns in Salisbury Pond and information on best management practices (BMPs).

## 2.1 Stormwater Management Plans for Universities

There are numerous college campuses' that have developed stormwater management plans in the past few years. In sections 2.1.1-2.1.4, the different universities stormwater management plans are outlined.

### 2.1.1 University of Pennsylvania

The University of Pennsylvania was founded in 1740 and the construction of the first building began at Fourth and Arch Street in Philadelphia (UPenn 2014). UPenn's undergraduate body is composed of just over 10,000 members. The campus is just shy of 1,000 acres and has 357 buildings (UPenn, 2014).

The University of Pennsylvania developed a stormwater plan with the following goals in mind:

- To provide full compliance with PWD's goal of managing one inch of runoff from all impervious areas
- Review existing stormwater management systems on campus
- Review potential new stormwater management technologies that new construction or retrofit projects can utilize
- A block-by-block analysis of potential stormwater management opportunities, including considerations of future Penn Connects 2.0 projects
- A review of current and pending stormwater legislation that may impact future development on the campus
- A review of current grant or funding opportunities

These goals are similar to the goals for WPI's stormwater management plan.

At UPenn, stormwater runoff is not managed by facilities and most campus buildings have their roof downspouts directly connected to the City's combined sewer system via underground pipes (Duffiled Associates, 2013).

Stormwater Management technology is always evolving and changing as a result of regulation requirements changing as well. Regulations are aiming to create sustainable solutions that attempt to restore the natural hydrologic cycle by mimicking natural processes such as infiltration and bioretention1. With the regulations and goals in mind for a stormwater management plan, UPenn developed a block-by-block analysis of the campus, where they identified potential opportunities for stormwater retrofitting of existing buildings with green roofs; retrofitting of existing paved areas with pervious pavements; shared stormwater management facilities; and possible options for future construction of facilities (Duffield Associates, 2013).

The inventory areas on UPenn's campus are as followed:

- Total campus study area: 10,958,000-$ft^2$
- Total Roof Area: 4,051,000-$ft^2$
- Total Ground-Level Impervious Area: 3,787,000-$ft^2$
- Total Impervious Area: 7,838,000-$ft^2$

The study area is approximately 72 % impervious and with one inch of runoff from all campus impervious surfaces generates a stormwater volume of 4,900,000 gallons of water. There are some major challenges with managing one inch of runoff from all the University's impervious surfaces with the Philedalphia Water Deparment's regulations for the entire campus.

At UPenn, a green roof system is an extension of the existing roof, which involves a high quality waterproofing, and root repellent system, a drainage system, and filter cloth (Duffield Associates, 2013). According to PWD regulations, a green roof with a minimum growing medium thickness of three inches provides sufficient storm water management (Duffield Associates, 2013). Green roofs reduce stormwater construction costs and PWD stormwater fees but also have other benefits. A green roof acts as an additional insulation and can reduce heating and cooling costs. The green roof has significantly exceeded the life span of a conventional roof so over time money will be saved.

In the past capturing and reusing stormwater has been practiced, but in the last few decades this practice has been adopted in United States urban settings. Due to the low cost of public water and the added cost of constructing a water treatment system and a secondary plumbing system, the economics of this practice can be difficult to justify. However with the combination of new construction methods, rainfall catchment area and water demand the practice of reusing stormwater could be economically desirable and operationally feasible. The capturing and reuse of stormwater is in UPenn's future stormwater management plans and is on their radar for upcoming years if the advantages outweigh any disadvantages.

Similarly to how WPI Facilities views existing infrastructure and stormwater management, UPenn divided the campus in 32 "blocks" in order to evaluate stormwater management opportunities on a smaller, more detailed scale. For each block on campus, displayed in Figure 2, UPenn sectioned it off and focused on existing stormwater management procedures and opportunity for new stormwater management practices. Below is an areal view of the campus broken into the different blocks.


Block-by-block division of the University of Pennsylvania study area

**Figure 2: UPenn Campus Blocks (Duffield Associates, 2013)**

After much review, planning and strategizing, a list of recommendations was made for 0 to 6 months, 6 months to 5 years, and beyond 5 years. There were also general recommendations that should be considered as a basis for all stormwater planning. The first recommendation is to pursue increased stormwater management on a block-by-block approach rather than a campus-wide approach. Another recommendation is to ensure all new land development and redevelopment projects should strive to provide a 20 percent reduction in impervious area as compared to pre-development conditions. Another goal is for management of the first one inch of runoff from impervious surfaces for new and retrofit projects, ideally via infiltration if soil conditions permit. Also, another recommendation is for UPenn to consider increasing the storage capacity of stormwater management facilities on new projects to accommodate the future connections of adjacent existing buildings and runoff from impervious areas. Also, it is recommended that when a building roof is scheduled for repair or replacement, to consider the addition of a green roof if the existing structure will support it. Altogether it would be beneficial for the university to consider investing in green roofs as a signature feature on campus. Another strong attribute to a stormwater management plan, if feasible and cost worthy, is to install pervious pavements for all new impervious areas. This would reduce the need for subsurface infiltration and detention systems. In whole, it simplest way to reduce stormwater management requirements is to reduce impervious areas.

### 2.1.2 University of Wisconsin- Arboretum

The university of Wisconsin-Madison Arboretum is a research facility located within Dane Country, Wisconsin. Arboretum is a 1,260-acre multi-disciplinary teaching and research facility that works to conserve and restore Arboretum lands.

The University of Wisconsin developed a stormwater management plan to serve as a road map for addressing degradation of the Arboretum landscape from stormwater that comes from land surround Arboretum. (McSweeney, 2006). Prior to settlement, the land now occupied by the University of Wisconsin Arboretum used to absorb rainfall into the soil without much runoff to Lake

Wingra (McSweeney, 2006). Today impervious surfaces contribute to stormwater runoff into urbanized watershed and Lake Wingra.

This stormwater management plan was developed to mitigate stormwater runoff through the following:

1. Developing Arboretum management policies and procedures, as they pertain to storm water management.
2. Designing, budgeting and implementing of storm water management infrastructure on Arbore- tum property.
3. Coordinating and collaborating with surrounding municipalities and other watershed partners on issues related to storm water management.
4. Developing research and outreach education activities that utilize or are affected by storm water runoff.

Wetlands and upland woods originally surrounded Lake Wingra, but over the last 150 years, this area has been taken over by urban development. In Figure 3 below, it is clear that there was no development around Lake Wingra in 1834.

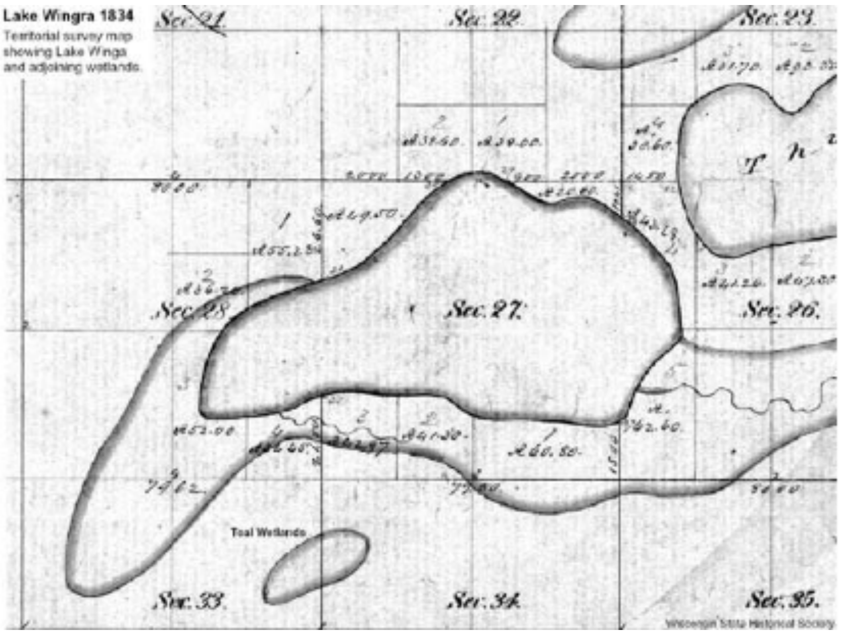


**Figure 3: Land around Lake Wingra 1834 (McSweeney, 2006)**

Comparing the figure above to Figure 4 below, the development has grown exponentially. In 1989, there is little to no open land.

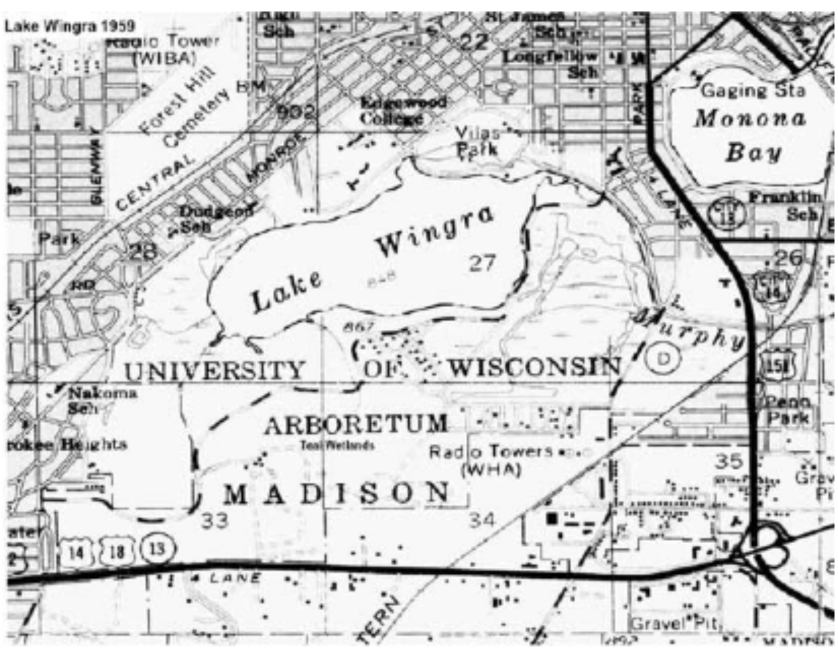


**Figure 4: Land Around Lake Wingra, 1959 (McSweeney, 2006)**

In Figure 4, Lake Wingra is surrounded by a mix of residential, commercial, and industrial land use. The area surrounding Lake Wingra contributes an average of 470 million gallons of stormwater runoff per year. (McSweeney, 2006). As development increased, there was an increase of stormwater runoff and as runoff increased stormwater infrastructure began to deplete.

### 2.1.3 UMass Boston

UMass Boston has an undergraduate body of nearly 16,000 and is the second largest campus in the UMass system (UMB, 2014). At UMass Boston, the stormwater that does not infiltrate into the soil, flows into storm drains and flows through underground pipes eventually to end at the Boston Harbor (UMB, 2014). UMass Boston has been developing and natural ground surfaces are changing to hard, paved surfaces. As more hard surfaces, such as: roads, parking lots and buildings are built, the amount of stormwater that can infiltrate into the ground decreases.

UMass Boston’s storm drainage system discharges directly to Savin Hill Cove and Dorchester Bay, both of which make up a larger Boston Harbor watershed (UMB, 2014). This stormwater runoff is not treated for pollutants before it reaches the Harbor. According to the State Department of Environmental Protection, Boston Harbor is identified as an impaired water body based on the following pollutants: priority organics, pathogens, suspended solids, and turbidity. Due to the campus's contribution to this water body, it is important for them to address stormwater runoff from the campus.

Due to UMass Boston's contribution, they developed a Stormwater Management Plan to address stormwater regulations and the operations and maintenance of stormwater management systems (UMB, 2014). For this stormwater management plan, the university applied for the Municipal Separate Storm Sewer System Phase II General Permit under the National Pollutant Discharge Elimination System. Under this permit, UMass Boston has implemented various best management practices to reduce the potential for pollution due to stormwater runoff. Some of the practices UMass Boston conducts are annual parking lot sweeps, catch basin cleaning and training of facilities personnel.

**2.1.4 Duke University**

Duke University was founded in 1838 and is located in Durham, North Carolina (Duke, 2013). Duke is home to about 13,000 undergraduate and graduate students and is 8,709 acres large (Duke, 2013). The campus is divided into three areas: East Campus, Central Campus and West Campus. In total, the campus is approximately 1,700 acres including three campus areas, golf course, primate Research Center, and a few outlying parcels (Titan Atlantic Group, 2002).

In North Carolina, stormwater regulations have developed considerably over recent years. Under the Federal Clean Water Act, the NPDES program was established and delegated to the Division of Water Quality for implementation in North Carolina. Under the City of Durham, Duke University is strictly held to all stormwater regulations. Duke University is committed to following the stormwater rules not only in the short-term but also in long-term as well. For that reason, a Stormwater Management Plan was developed as a tool for Duke University. (Titan Atlantic Group, 2002).

The majority of Duke University's stormwater runoff flows south into the Cape Fear River Basin. Duke University has mapped stormwater drainage systems and converted all mapping to electronic CAD files with notes of pipe sizes and pipe materials (Titan Atlantic Group, 2002). In order for best mapping, an aerial photograph was taken showing the stormwater collection system and watershed drainage basins. Also, the photograph displayed existing pervious and impervious surface areas. The university's drainage system itself, along with the soil layers beneath the campus surface act as storage zones. All watersheds are on the map and represent all the land area that drains to a specific point. For each sub-basin, the existing location, size and slope of all catchment structures, pipes and drainage swales and streambeds are noted. The City of Durham has been monitoring and surveying the stormwater drainage system and data have been incorporated into the base maps for the management plan.

The main goal of the stormwater management plan is to prevent increase in the amount of stormwater runoff volume that flows from Duke University. It is also expected that the plan would prevent any increase of the rate at which runoff leaves the campus and the pollutant load conveyed in that runoff. With these goals in mind, Duke University selected the EPA Storm Water Management Model (SWMM) as a program that utilizes state-of-the-are distributed flow routing methods to measure runoff quantity and quality.

Due to construction on campus, the percent imperviousness has increased with a range of 0.39% to 23.86%. Over different areas on campus, the percent increase was different due to higher or lower construction and development. As the campus continues to develop, the SWMM will monitor the changes in stormwater quality and quantity.

### 2.1.5 Summary of University Plans

University of Pennsylvania, University of Wisconsin, University of Massachusetts, and Duke University are all advancing universities working towards higher levels of sustainability. The universities all have made great strides in creating a stormwater management plan for their campus. UPenn has divided their campus into blocks and identified different BMPs for the different blocks. Some BMPs were stormwater retrofitting of existing buildings, and installation of green roofs, installation of pervious pavement. University of Wisconsin stormwater management plan was less detailed and served as a roadmap for stormwater. The main concern at University of Wisconsin is the depletion of landscape surrounding a major lake so their needs were less extreme. UMass Boston created a stormwater management plan and applied for a NPDES permit that would help with the following best management practices:

annual parking lot sweeps, catch basin cleaning and training of facilities personnel. Duke University converted all stormwater drainage systems to CAD files. They cad files include information on pipe size, material, exact location, and slope of each drainage system. In addition to this, Duke has begun construction of permeable pavements on multiple areas of campus. For each university, the plans and best management practices all vary. Stormwater management plans should be unique to the needs of the campus. For WPI, Massachusetts's regulations, City of Worcester permitting, and environment surrounding the campus will be reviewed before creating the stormwater management plan.

## 2.2 Massachusetts and Worcester Current Stormwater Plan

Massachusetts and the City of Worcester both have regulations and permits that will influence the content of a stormwater management plan for WPI. In 1996, a Stormwater Policy was issued that established Stormwater Management Standards aimed to prevent stormwater discharges from contributing to the pollution of waterbodies (EPA Energy and Environmental Affairs, 2008). The standards promote increased stormwater recharge, treatment of more runoff from polluting land uses, low impact development techniques, pollution prevention, the removal of illicit discharges, and improved operation of stormwater Best Management Practices (BMPs). Projects in Massachusetts that seek to comply with the Stormwater Management standards to the maximum extent practicable shall demonstrate the following (EPA Energy and Environmental Affairs, 2008).

- All reasonable efforts to meet each of the standards

- Complete evaluation of possible stormwater management measures, including environmental sensitive design, low impact development, structural stormwater BMPs, pollution prevention
- If full compliance with the standards is not achieved, they implement the highest practicable level of stormwater management.

For the different projects, the amount of detail in the plans should reflect the level of complexity and nature of the project. Massachusetts governs the different towns, cities, and individual residents and projects in each of these towns.

Under Massachusetts Stormwater Management Handbook, there are suggested BMPs for stormwater management projects under its governing towns. The pretreatment BMPS include: deep sump catch basins, oil/grit separators, proprietary separators, sediment forebays, and vegetated filter strips. The treatment BMPs include dry detention basin, green roofs, pervious pavement, rain barrels and cisterns.

The City of Worcester developed a stormwater management plan to fulfill the requirement of the Environmental Protection Agency's (EPA) National Pollution Discharge Elimination System (NPDES) Stormwater Permit. The purpose of the plan is to summarize all aspects of Worcester Department of Public Works' efforts to reduce stormwater pollution from its Municipal Separate Storm Sewer System (MS4) to the maximum extent practicable (City of Worcester, 2008). The plan is a collection of Best Management Practices (BMPs) as recognized under the MS4 as a way to minimize stormwater pollution (City of Worcester, 2008). The City of Worcester broke the plan down into seven sections with each section focused on a specific Best Management Practice.

The main sections are as followed:

1) Overview of the plan

2) Existing and new regulations

3) BMPs to educate citizens of Worcester

4) "Source Control" BMPs to prevent or reduce pollutant entry

5) Maintenance BMPs to keep MS4 in proper running order

6) BMPs designed to improve MS4 infrastructure

7) Stormwater Monitoring Program to determine MS4 discharge quality

These sections and BMPs are all designed to decrease stormwater pollution and increase the quality of Worcester stormwater discharge.

In section two of the stormwater management plan, the City implements two BMPS to aid in the reduction of stormwater pollution from industrial sources. The first BMP is the implementation of tracking industry ownership changes. GIS system, and specifically, the layer that tracks industry ownership will be updated frequently to provide up to date information, aiding in the EPA's efforts to enforce industrial stormwater permitting. The second BMP in section two involves sewer use regulation enforcement for industries. This BMP regulates and enforces actions taken by industries not in compliance with the DEP and EPA.  There are also two ordinances that require public works committee and city council approval. The first ordinance proposed that all “yard clipping” materials do not get discharged into any public sewer, which will decrease the loading of oxygen-demanding substances. The second ordinance enforces that pet owners throughout the city are responsible for clean up after their pets.

Section three discusses the best management practices for education and outreach. This section is designed to outline processes to inform residents and city officials about the stormwater pollution, its causes and effects, and their role in reducing the impact of stormwater pollution on the environment (City of Worcester, 2008). The basic elements for this plan include:

- Installation of “City of Worcester Waterway” Signage
- Stenciling of catch basins
- Participation in stormwater education program
- Publication and distribution of quarterly newsletters and pamphlets
- Partnership with area grassroot organizations whose focus is on water quality issues

Education of residents and city workers is essential to the improvement of Worcester’s stormwater pollution.

Section 4 discusses the practices that best prevent pollution, also known as source controls. These source controls prevent pollution from entering the MS4, are multi jurisdictional and involve cooperation between city departments and state and federal agencies. This section mainly discusses:

- Facilities Management
- Oil Collection and Recycling
- Spill Response
- Use Reduction
- Household hazardous Waste Collection
- New Construction and Redevelopment controls
- Pesticide Controls

Section 5 focuses on the maintenance of storm drainage systems. A large amount of stormwater pollution that enters the MS4 comes from Worcester drainage systems. Some best management practices include:

- Street Sweeping
- Catch Basin Maintenance
- Sewer System Root Control
- Sewer Operations Division Standard Operating Procedures
- Coordination with the Massachusetts Highway Department

These practices reduce the amount of sediment and heavy metals from entering the sewer system. The City of Worcester is implementing new catch basin cleaning methods. Also, for the two main highways running through Worcester, Interstates 190 and 290, the city has become familiar with Massachusetts Highway Department and will coordinate with them throughout the permit term to increase mechanical sweeping and cleaning.

Section 6 is designed to improve the storm drainage system infrastructure. This is an important aspect to the stormwater management plan because in heavy rainfall, the storm drain may surcharge which allows access of inflow into the sanitary system. To prevent this, these five best management practices were designed:

- Installation of twin-invert manhole hold-down devices
- Detection and removal of illicit connections to the storm drainage system
- Maintenance of retention and detention ponds
- Paving of unpaved streets
- Performance of structural control demonstration project

Some of these practices are difficult, slow, and labor intensive but will unquestionably reduce the pollution in the MS4 and receiving waters.

The last section of Worcester Stormwater Management plan, section 7, is sampling and monitoring program, which targets one watershed each year. This allows for increased focus of locating, isolating and correcting pollutant sources. These programs begin with dry and wet weather field screening of major stormwater outfalls once during the permit term. Also, wet weather sampling will be taken at five outfall locations in the City three times a year, each year of the permit term and an additional instream sampling of two sites during the same wet weather events.

### 2.2.1 Current Permitting and EPA Information

Currently the City of Worcester is operating under the 1998 permit (Permit No. MAS010002). The permit covers discharges through municipal separate storm sewer systems, stormwater pollution, wet weather monitoring and reporting, and dry weather discharges.

The permit authorizes all stormwater discharges to waters of the United States from all existing or new outfalls (City of Worcester, 1998). The permit also regulates stormwater discharges that are comingled with wastewater, non-process wastewater, or industrial activity stormwater. It states that the mingled discharge are authorized under separate NPDES permits and are in compliance with applicable Federal, State and local regulations (City of Worcester, 1998).

In addition to the municipal systems, the permit regulates stormwater pollution and management. The permit states that there should be implementation of "a stormwater pollution prevention and management program designed to reduce, to the maximum extent practicable, the discharge of pollutants from the Municipal Separate Storm Sewer System (MS4)" (City of Worcester, 1998). This shows that the permit requires the permittee to do the best they can and try to reduce as much pollutant as possible. The prevention plans should follow these main steps:

1. Development: The plan should take into account the new development or significant re-development that may contribute to the pollution that is picked up in stormwater

2. Used Motor Vehicle Fluids: The plan should include an education piece to inform the public on recycling, reusing and disposing of motor vehicle fluids.
3. Household Hazardous Waste: The plan should enforce that households recycle, reuse or dispose of hazardous waste materials including: paint, solvents, pesticides, herbicides, and other hazardous materials

To reduce pollutants, the permit requires that SWMPs include controls that reduce the discharge of pollutants. In addition, the permit states that each catch basin is cleaned at least every other year and the cleaning program must include recordings of date, location and estimated volume of each catch basin (City of Worcester, 1998). In addition, the permit suggests controls designed to minimize pollutants from new development and construction and significant redevelopment construction (EPA, 2013). Pollutants from construction are easily picked up by stormwater and can have significant negative effects on water quality (EPA, 2013). Stormwater can pick up debris, sediment, and chemicals and runoff into water bodies, which can harm or kill marine life.

The permit also regulates wet weather monitoring and reporting. It is important to assess the effectiveness and adequacy of control measures. These control measures should estimate concentrations and seasonal pollutants, and quality and quantity of pollutants discharged from the MS4. There should also be monitoring systems and sampling stations to test and characterize the stormwater discharge. These locations should be tested at least three times per year to ensure they are upholding permit requirements throughout the main seasons. In addition to wet weather testing and monitoring it is important to test during the dry weather periods. During dry weather periods it is essential to test for illegitimate connections and improper disposal (City of Worcester, 1998). Each year under this permit the city of Worcester must submit a report outlining:

1. Update on Stormwater Management Program(s)
2. Proposed changes to existing SWMP
3. Revisions or amendments to the assessments of controls and fiscal analysis
4. Evaluation of non-storm water discharges
5. A summary of the data collected from the monitoring and collection
6. Revised list of all separate storm sewer outfalls
7. Annual expenditures and budget for the upcoming year
8. Summary of enforcement actions, inspections, and public education programs
9. Water quality improvements or degradation
10. Update on illicit connections

Every ten years the permit that the City of Worcester operates under is redone. In 2008 the permit was revised and is currently still pending approval.

### 2.2.2 Future Permit Proposals

There has been some disconnect and disagreements between the City of Worcester and the EPA in regards to stormwater management plans and permitting. The current SWMP does not sufficiently address all required elements needed. The EPA has sent a letter to the City of Worcester specifying the sections that needed more information (City of Worcester, 1998). After a year, the City of Worcester sent a letter addressing the concerns presented by the EPA but there was still information missing and some details were insufficient. The main issues that the EPA sees are: the sampling plans, instream monitoring, pollutant peak and loadings, and catch basin cleaning and inspection (City of Worcester, 1998).

The proposed permit (Permit Number MAS01002) has not been made effective yet. This updated permit follows a similar format and has similar requirements and regulations; however, additional and more detailed regulations have been added. Under the discharge authorization, there is a section that states discharges must not exceed water quality standards. Also, instead of stating that the city should do as best they can to reduce pollutant, this updated permit requires the reduction of pollutants to the maximum extent practicable. If the EPA or MassDEP determine that discharge causes or contributes to an exceedence of standards, actions will be taken (City of Worcester, 2008). There is a new section added to this permit outlining pollutants and requirements for the reduction of them. The regulations are much more strict, developed and detailed in comparison to the 1998 permit. The ten-year difference has resulted in huge strides and improvements.

## 2.3 Salisbury Pond TMDL

The MassDEP is responsible of monitoring the waters of Commonwealth, identifying those waters that are impaired, and developing a plan to bring them back to compliance with the Massachusetts Water Quality Standards (Durand, Giles, Haas, 2002). Salisbury Pond is one of the water bodies that are monitored by the MassDEP.

Salisbury Pond is a 15-acre municipally owned pond, located adjacent to WPI campus, in the headwaters of the Blackstone River Watershed Worcester, MA. This area is highly developed with a large percentage of impervious surfaces (Durand, Giles, Haas, 2002). Because of this, Salisbury Pond continually breaks violations for water quality. After testing, Salisbury Pond was listed for having Nuisance Aquatic Plants and turbidity associated with high phosphorous loadings (Durand, Giles, Haas, 2002). In order to ensure that Salisbury pond meets regulations for water quality standards, the TMDL established a phosphorous limit for the pond.

The TMDL for Salisbury Pond should be 1,082 kg/yr total phosphorous (Durand, Giles, Haas, 2002). Studies found that the phosphorous levels almost always exceeded the 0.02 mg/l and the total annual phosphorous loading was 4,646 kg/yr. This value is quadruple what is set forth in the TMDL. Table 2.1, displays the current total phosphorous and the target phosphorous for different inlets into the pond.

**Table 1: Current TP vs. Target TP** (Durand, Giles, Haas, 2002)

| *Source* | *Current TP Loading (kg/yr)* | *Target TP Load Allocation (kg/yr)* |
|---|---|---|
| **Load Allocation:** | 0 | 0 |
| **Waste Load Allocation:** | | |
| Twin Culvert Inlet * | 4480 | 888 |
| Drain #4 Stormflow | 149 | 123 |
| Other drains & runoff | 17 | 17 |
| **Total Inputs** | 4646 | 1028 |

The highest TP loading is from the Twin Culvert Inlet, which is mainly high due to runoff from Massachusetts Highways, mainly I-90. From table 1, it is clear that the WPI runoff that enters the pond in Drain 4 is not as detrimental as the other inlet. However, it could still be improved to meet the target TP.

## 2.4 BMP Options

The Massachusetts stormwater handbook recognizes best management practices for stormwater management plans. To have the highest reduction from WPI campus entering Salisbury pond different best management practices were researched and considered for implementation at WPI. Some background on Green Roofs, Retention Ponds, and Permeable Pavements as BMPs can be found in this section.

### 2.4.1 Green Roofs

A green roof is designed to provide a layer of vegetation that primarily helps manage stormwater in urban environments. Green roofs have been shown to be effective at reducing the volume and peak flows of stormwater. However, green roofs are not always the best option for New England weather where patterns vary day-to-day (Lepage, 2010). For WPI, the majority of area is covered in buildings. While this may seem like a good option for WPI's stormwater management plan there are some considerations that make it an unreasonable alternative. For this design, there would need to be a new design added to each building. Some buildings are their original structure when built in the late 1800s. While this can be an option for future building construction, it is not feasible to add a green roof to the existing buildings. This would be a costly endeavor for just one building and to reduce the stormwater runoff significantly, multiple buildings would need remodeling.

### 2.4.2 Retention Ponds

Retention ponds are constructed basins that have a permanent pool of water throughout the year, primarily throughout the wet season (EPA, 2012). These ponds would treat incoming stormwater runoff by allowing particles to settle. The primary removal mechanism is settling as stormwater runoff resides in the pool. Although these are a great option for stormwater management plans, they have limitations in highly urbanized settings.  The retention pond would need a sufficient drainage area to maintain the permanent pool. Retention ponds need a large amount of area in order to be efficient. On WPI campus, there is not a significantly large area that could be repurposed for the design of a retention pond. The retention pond of this size can pose safety hazards. With the population on campus, it is a huge risk to have the retention pond.

### 2.4.3 Permeable Pavements

Permeable pavement designs will reduce stormwater runoff volume, rate and pollutants (EPA, 2009). The interconnected void space in permeable pavements allows for stormwater to flow through and enter a crushed stone-bedding layer. When properly constructed, permeable pavements are a durable and competitive alternative to conventional pavement (EPA, 2009). Pervious pavement can replace traditional impervious pavement for most pedestrian and automobile usage. For WPI, there is a high amount of impervious surfaces that can be replaced with permeable pavement. Two types of pervious pavement that can be used are: pervious concrete and pervious asphalt.

Pervious concrete is typically used for parking areas, driveways, sidewalk, and roadways (Huffman, 2008). It has environmental benefits because of the void areas in the pavement that allow significant infiltration. Concrete is a lighter color with higher light reflectivity. It has a longer service life because it is extremely durable with the ability to bear heavy loads (Huffman, 2008). Pervious concrete is a more expensive option for pervious pavement.

Pervious asphalt is a cheaper option pervious concrete but has fewer advantages to concrete. It is a dark color and therefore absorbs more heat. It has a shorter lifespan to concrete (Huffman, 2008). Although it has a shorter lifespan it is still a durable pavement. Pervious asphalt has a quick construction time. The lower cost for pervious asphalt comes with fewer advantages compared to pervious concrete.

After reviewing information from different university plans, the current permitting of Massachusetts and Worcester, and the BMP options, the information will be altered to fit the needs of WPI campus. The focus of the project will switch to analyze the current conditions of WPI and potential for design as a part of the stormwater management plan.

# 3.0 Methodology

To create a WPI Stormwater Management Plan and design component intended to reduce the runoff entering Salisbury Pond, the multiple steps taken for the methodology were to:

- Multiple layers were added GIS map to track runoff and analyze pervious surfaces.
- Flow and load calculations were used to quantify runoff of the different areas, and
- Priority areas were identified that could potential for development of best management practices (BMPs)
- Flows and loads estimated for the priority areas
- Permeable pavements were designed as BMPs to reduce flows and loads entering Salisbury Pond

The methods associated with these tasks are included in this chapter.

## 3.1 GIS Analysis

Arc GIS is a tool used for both macro and microanalysis due to its wide range of functions and ability to provide varying degrees of precision. It is, however, only as useful as the information added, so it is imperative to know what to include and reasons for adding it. A GIS map has been created for Worcester Polytechnic Campus and the surrounding area. The goal and purpose of this GIS model is to map out the storm water paths on campus and show how it impacts local water bodies.

### 3.1.1 Town Lines

The first layer added to the map is town line, which provides a general reference for campus. Although we are only concerned with Worcester, multiple municipalities often drain to different water bodies, so the other municipalities must be acknowledged. This town line layer will be helpful in seeing which storm systems overlap into different towns, if any and in specifics into Worcester.

### 3.1.2 Water Bodies

The next layer added is said water bodies, which make up the majority of the city's fresh water supply. Knowing where water bodies are located is imperative to devising a management plan, as the end goal is to reduce pollutants and improve water quality. With addition layers showing underground infrastructure, catch basins, piping, contours, and inlets this water body layer will be extremely helpful in seeing where WPI's water goes.

### 3.1.3 Worcester CSO

The next phase of GIS mapping is to add in details, and as we are dealing with storm water one of the most important details is how it's currently dealt with. Worcester is divided into two regions for storm water control, the combined sewer region and the area outside this region. The CSO has catch basins flowing directly into the sewer system, and then off to the treatment facility, where everything outside this region flows directly to discharge points. When combined with a roads layer, we can begin to develop a picture of how runoff is channeled and discharged. Roads create impervious surfaces, which disrupt natural runoff paths and create high velocity channels for flow to travel. The specific road layer added not only includes direction, but also shape of areas, which can be used to account for total impervious surface area when it comes time for analysis. Now, however, they add additional references to put further layers into perspective. From the reference of the roads and the town lines, we can determine that the target area, WPI campus, is to the west of the CSO and the runoff is not treated before discharge.

### 3.1.4 Worcester Buildings

The next addition is buildings, which typically make up the majority of impervious surfaces in a municipality. Buildings tend to be large, flat, and until very recently didn’t have any design considerations to reduce runoff volume or speed, merely being concerned with getting water off the tops to prevent interior damage. Additionally, the presence of buildings on the map provides further reference when it comes to distance between catch basins and how runoff has to travel from point of precipitation. Buildings are also one of the most important components of storm water modeling, due to how they can drastically impact the direction, volume, and speed of runoff.

### 3.1.5 Worcester Driveways and Walkways

Despite the valuable layers included, there is still area to improve and layers which, if found, will make the map an even better analysis tool. Desired additions to the GIS map are layers, which include grassy, or at the very least non-impervious, surfaces in the city of Worcester. This is the other half of the storm water modeling process, and without a handle on how much pervious area there is, it would be impossible to have accurate final models. Along the same vein is the inclusion of a sidewalk or walking path layer for WPI, as the campus has a large number of bricked walkways throughout the main campus which, although have less area than building surfaces, contribute to accelerated runoff. This desired layer may not exist, however the possibility exists to create one from aerial photographs of campus scaled to the existing buildings layer. This could take considerable work, but would result in more accurate models in the end. The last major desire for the GIS map is to identify catch basin discharge points. Knowing their destination is just as, if not more important than knowing where they are in the first place.

Despite how helpful the GIS map is for determining the current conditions of the WPI campus in terms of storm water and runoff discharge, it is only the first step in the storm water analysis process. The conclusions drawn from the GIS map of campus can be combined with information directly gathered from WPI facilities and the city of Worcester to finalize the picture of current storm water conditions and the environmental quality of Worcester at large so that we may devise an effective and practical storm water management plan.

## 3.2 Flow/Load Quantification

To analyze data and runoff, different models and methods were used. There are simple methods that can be used like the rational or modified rational method. This allows one to produce estimates of peak runoff rates using limited rainfall and drainage area data but will not be able to predict total runoff volumes.

The total amount of rainfall has the most influence on runoff volumes. However, runoff rates that resulted from a given rainfall, including peak rate or discharge, are influenced the most the rainfalls distribution. The distribution is described as how the rainfall rate or intensities vary over a period of time. Rain events can vary immensely from event to event. To account for rainfall variability there are two general solutions. Multiple methods, like the Rational and National Resources Conservation Service (NRCS) methods rely on a hypothetical rain event known as a design storm for their rainfall input. This hypothetical storm that is used is based on a compilation of local or regional rainfall data that had been recorded over an extended amount of time. Some previous assumptions must be made in order to use a design storm about the antecedent ground and waterway conditions that exist at its start.

Soils in the watershed and the type of surface that covers those soils can also have in impact on the runoff volume and peak discharge. This could be that the area is covered in trees, has been paved over, or buildings put up. Knowing what areas are impervious and which ones are pervious affects runoff. Time of concentration in a single are can also affect runoff. Time of concentration can be affected by surface roughness, irregularity, length, and slope. Listed below are the characteristics of the rainfall and the influence it has.

1. High intensity rainfall will generally produce a greater peak discharge than a rainfall that occurs over a longer time period.

2. Highly pervious or permeable soils that can rapidly infiltrate rainfall generally produce less runoff volume than soils with more restrictive infiltration.

3. Dense vegetation such as woodland intercepts and help infiltrates rainfall, thereby reducing runoff volumes and rates.

4. Conversely, impervious areas such as roadways and rooftops prevent infiltration and increase runoff volumes and rates.

5. Drainage areas with shorter times of concentration will have higher peak runoff rates than those with a longer Tc.

To calculate flow and load calculations for WPI surfaces, the TR-55 method was used. Worcester falls under the type III storm distribution and soil classification C. Rainfall was graphed for 1, 2, 5, 10, 25, 50, and 100-year storms. Calculations can be found in Appendix D. The percentage of total rainfall was calculated and the percent infiltration was graphed. These calculations and graphs were used to analyze which areas on campus would have the biggest impact from a BMP design.

### 3.3 Identification of Priority Areas

In order to create the most beneficial stormwater management plan, all areas of campus were analyzed to see which area on campus would have the biggest impact in reducing volume runoff. Controlling the volume of runoff is something that this stormwater management plan has the most control over. Although we can control somewhat the pollution in the runoff, the volume of runoff can easily be reduced with the proposed design alternative of permeable pavements.

Using GIS the areas of three main impervious surfaces were tracked. The three biggest impervious surfaces on campus are:

1. Boynton Parking Lot/Library Lot
2. Quadrangle Area
3. Goddard Hall Area and Service Access Road

### 3.3.1 Topography of Areas

In addition to the size of each area, topography was analyzed. Topography describes the shape and relief of the land. It is a measurement of elevation and the slope over a certain distance (Tompkins, 2004). The topography was examined using GIS contour lines. These lines displayed the different slopes and curvatures of WPI's campus. This feature is important when considering a stormwater management plan for multiple reasons. With flat lands, the construction cost will be lower and therefore more appealing when deciding on an executive level. Also, areas with a higher slope will have less water infiltration and will have the smallest impact with permeable pavements.

## 3.4 Process for developing a Stormwater Management Plan

Without an existing stormwater management plan for WPI, a lot of background research was completed to create one. First, stormwater management plans for UPenn, University of Wisconsin, UMass Boston, and Duke University were reviewed and evaluated. Reviewing requirements for management plans for municipalities and other entities with stormwater discharges was important to compare to the needs of WPI. Steps were developed to reflect the needs of WPI. Some considerations that went into the major steps of the plan were: size of campus, climate patterns, percent pervious area, surrounding water body quality, biggest area of impact, and feasibility of different best management practices.

# 4.0 Stormwater Management Plan

WPI is an innovative, growing and sustainable campus. With the new addition of LEED certified buildings, improvements to existing buildings, and future goals to improve different areas of campus, a stormwater management plan fits in with the long-term goals of WPI. For this project, a stormwater management plan was created to help accomplish the goals of the project to reducing the volume of runoff entering Salisbury Pond. This plan contains an overview, public education and outreach, illicit discharge detection and elimination, construction site control measure, post-construction site control measure, and pollution prevention control measures.

## 4.1 Overview of the Plan

Although there have not yet been permits issued, it is required that operators of small MS4s to (EPA, 2008). The guidelines specified in the MS4 program provide a guide for developing stormwater management plans for other organizations. Accordingly, the EPA guidelines were used to develop a basic plan for WPI. First the plan should be created with measurable goals as guidelines. EPA suggests developing and implement a stormwater management plan with control measures or best management practices to fulfill these goals. The plan should also include an evaluation of the effectiveness of the program.

The measurable goals for the stormwater management plan were to:

1. Reduce the volume of stormwater runoff from WPI campus
2. Create an effective and cost efficient best management practice that will significantly reduce runoff
3. Create a sustainable and low maintenance best management practice

To best meet the goals listed above, minimum control measures must be incorporated into stormwater management programs. Following these control measures can reduce the volume and amount of pollutant discharge into waterbodies. The following controls are recommended for WPI: Public Outreach and Education, Illicit Discharge Detection and Elimination, Construction Site Runoff Control, Post-Construction Site Runoff Control, and Pollution Prevention/Good Housekeeping. A test plot will be used to evaluate effectiveness of the plan. The plan should be reviewed by WPI to seek gaps and areas of improvements in the plan.

## 4.2 Public Education and Outreach

The first control measure is public education and outreach. WPI has approximately 6,500 undergraduates, graduates, and faculty that use the campus. With a large community like this, it is essential to involve them in the plan. The public will gain a greater understanding of the reasons why there is a plan, what is does, and how they can help (EPA, 2008). The approach to involving the public will be with signs, displays and education programs.

### 4.2.1 Signs and Displays

The first part of the education component is advertisement. Recognizing the audience being targeting is important to know what type of advertisement will be used. Signage should be posted near a test plot design, and near the Boynton Parking Lot. Some signs can be eye catching and draw attention and others can have detailed information informing the community on the plan. The audience should know where stormwater runoff goes, and what the effects of stormwater runoff are. Most construction sites and design projects have signage to inform the community on the changes being made. Without this education, the WPI community will not understand why a best management practice is being put into place. For example, the community should be informed of why permeable pavement are a preferred best management practice opposed to regular pavement. Additional forms of education can be in brochures, fact sheets, and education programs. All information can also be posted on the WPI Sustainability web page.

### 4.2.2 Education of where Pollutants go

WPI is a growing and sustainable campus with a large focus on greener initiatives. Currently, pollutant discharge in stormwater runoff is not a large issue on campus. Types of pollutants that are collected in runoff are: individual litter, sediments, oil leaks, fertilizer, and construction site runoff. It is important to inform the community of the types of pollutants in WPI stormwater and where they ultimately go. Education can be sent through email, signs, or information sessions. It will be important to show the contours of WPI land and show where their pollutants will go upon hitting the ground. Community discussions can also be conducted for education purposes. Community members can discuss their viewpoints, concerns, and provide input. It will be a good way of understanding the community perspective and how plans should be altered or how education can be improved.

## 4.3 Illicit Discharge Detection and Elimination

One of the required control measures for a stormwater management plan is illicit discharge detection and elimination. Each MS4 has a lot of flexibility when choosing exactly how to satisfy this control measure (EPA Office of Water, 2005). Illicit discharge is defined as any discharge that is not composed solely of stormwater. Illicit discharges can include sanitary wastewater, and effluent from septic tanks. Wastewater can sometimes contaminate stormwater and enter the piping systems. This would be a huge issue for Salisbury pond and the pollutants entering it. The region in the vicinity of WPI has been checked relatively recently, and extremely minimal amounts of illicit discharge were detected from WPI. It is still important to review the stormwater system to ensure no illicit discharges exist, so this requirement is included in the plan.

## 4.4 Construction Site Runoff Control

WPI is a growing institution with a lot of recent construction projects. These construction projects do include standard controls for managing sediments and runoff. It is well known pollutants will accumulate due to the construction. Some pollutants that will accumulate are sediment, solid and sanitary waste, phosphorous, nitrogen, pesticides, oil and grease, concrete truck washout, construction chemicals, construction debris (EPA Office of Water, 2005). These pollutants will become suspended into runoff and carried into the receiving waterbody. For the BMP recommended, construction will be required. It is recommended that preventative measures be included to mitigate the pollutants that can accumulate and discharge into the pond. The EPA requires that each plan has:

- An ordinance or regulatory mechanism requiring the implementation of proper erosion and sediment controls
- Procedures for site plan review of construction plans
- Procedures for site inspection and enforcement of control measures
- Have sanctions to ensure compliance
- Establishes procedures for the receipt and considerations of information submitted by public
- Determination of the appropriate best management practices and measurable goals for this minimum control measure

WPI should follow all of these regulations for construction sites. In 2003, NPDES regulations came into effect to extend coverage to construction sits that disturb one to five acres in size (EPA Office of Water, 2005). Even though all construction sites that disturb one or more acres are covered by NPDES regulations, there must be construction site runoff control measures to more effectively control construction site discharges. So even though WPI would be covered by NPDES regulations, the control measures to prevent construction runoff must be put in place. The construction of permeable pavements will include the demolishment of existing pavement, digging, installation, and paving. All of these steps require heavy machinery and will create a lot of pollutant runoff.

### 4.5 Post-Construction Runoff Control

Along with the construction runoff control, there needs to be post-construction runoff controls. The runoff after the conclusion of any construction still may have high levels of pollutants, which can contaminate water bodies. After the construction of the permeable pavement design, it will be important to follow the guidelines provided in this stormwater management plan. Prior planning and design for the reduction of pollutants accumulated in post-construction stormwater discharges is the most cost efficient way to control quality of stormwater (EPA Office of Water, 2005). In accordance with NPDES requirements, MS4 operators are required to:

- Develop and implement strategies which include a combination of structural and/or non-structural best management practices
- Have an ordinance or other regulatory mechanism requiring the implementation of post-construction runoff controls to the extent allowable under the state or local law
- Ensure adequate long-term operation and maintenance controls
- Determine the appropriate best management practices and measurable goals for this minimum control measure

The measurable goals for WPI can be determined to gauge permit compliance and reflect the needs of the post-construction. It will be important for WPI to provide appropriate cleanup, maintenance, and upkeep of the pavement after the construction to prevent pollutant runoff. WPI has had phenomenal control of the construction in the past. WPI is mindful of the contaminants produced while in construction and have efficient clean up procedures. Clean up procedures will be put in place for the construction of a permeable pavement design.

### 4.6 Pollution Prevention/Good Housekeeping

The last control measure for the stormwater management plan is pollution prevention. Part of the pollution prevention is mapping of source areas for stormwater generation, and tracking of stormwater flows and discharges. The GIS map of WPI campus shows the surface elevation contours, the stormwater pathways, catch basins, and the location where the effluent discharges into the pond. The GIS map, displayed in figure 1 and broken down into smaller sections in figures 7-9, demonstrates the basic intake and discharge areas of the system. It can demonstrate the possible sources of pollution. The EPA recommends that when developing a BMP, the problem area should be located first. Once the problem location is determined, the source of the problem should be determined. The next steps are to correct these problems, remove any sources, and then document the actions taken. After completing the EPA’s recommended steps, measurable goals and BMPs should be made to reflect the needs of the project. For WPI, the goals and BMPs should be made to reduce the runoff volume entering surrounding waterbodies.

This step does not only help protect the design and reduce pollutant runoff, it can also be a cost saver for the future. It can avoid repair costs from damage entering sewer systems. Following the NPDES recommendations, WPI should:

- Develop and implement an operation and maintenance program with the goal of preventing or reducing pollutant runoff
- Include training on how to incorporate pollution prevention techniques
- Determine the appropriate best management practices and measurable goals for this control measure.
- Maintain a program to review and evaluate potential best management practices

When developing this plan, WPI should consider the maintenance activities, schedules, and long-term procedures for the pavement design. The pavement upkeep should be reviewed and maintained as needed. The university should review the plan each year, specifically looking at reduction in runoff volume, infiltration amount, and pavement quality. If the pavement is not operating to full potential and meeting the goals of the plan, practices should be reviewed and adjusted.

The stormwater management plan will have main goals focused on:

- Reducing volume of stormwater runoff from WPI campus
- Creating an effective and cost efficient best management practice that will significantly reduce runoff, and,
- Creating a sustainable and low maintenance best management practice

The plan will meet these measurable goals by educating campus, detecting illicit discharge, following construction and post-construction site controls, and pollution prevention and upkeep. Reviewing the measurable goals and analyzing effectiveness of the plan is a crucial step to the plan. If the goals are not met and the plan is not effective, alterations and other best management practices should be considered.

# 5.0 Stormwater Analysis and BMP Design

After creating a stormwater management plan for WPI, the next step was to design a Best Management Practice (BMP) that would reduce the portion of stormwater runoff from the WPI campus that enters Salisbury Pond. To accomplish this goal, the following tasks were completed:

- A geographical assessment was completed for and land areas and storm drain systems the WPI campus
- Priority areas were identified
- Rainfall data were analyzed
- A permeable pavement option was designed as a BMP
- A cost analysis for the design was completed

After these steps and results were analyzed, conclusions and final recommendations were made.

## 5.1 Geographical Assessment

WPI is located on a total of 80 acres of land. Much of the campus sits on top of a hill and stormwater drains down through catch basins and manholes. Figure 5 displays a full view of the sp04 region in which WPI lays mainly. Some of the campus lay in other regions, but the scope of this project focused on sp04. Regions labeled SP are divided regions that runoff into Salisbury Pond. The tan areas are various buildings, the different colored small circles are catch basins, manholes, and drainage holes. The blue lines are the underground storm drain systems. The system located in sp03 is the main drainage system that WPI runoff flows through. Not all of WPI is located in sp04 and not all of the runoff enters through the storm drain system located in sp03. A majority of the runoff does flow through that system but some of the runoff from WPI enters different drainage systems. The scope of this project focuses on the runoff entering Salisbury Pond through this drainage system. A bigger scope of stormwater management should include Gateway Park located farther from campus and other areas of campus that drain through other storm drain systems. The figure is not to scale.

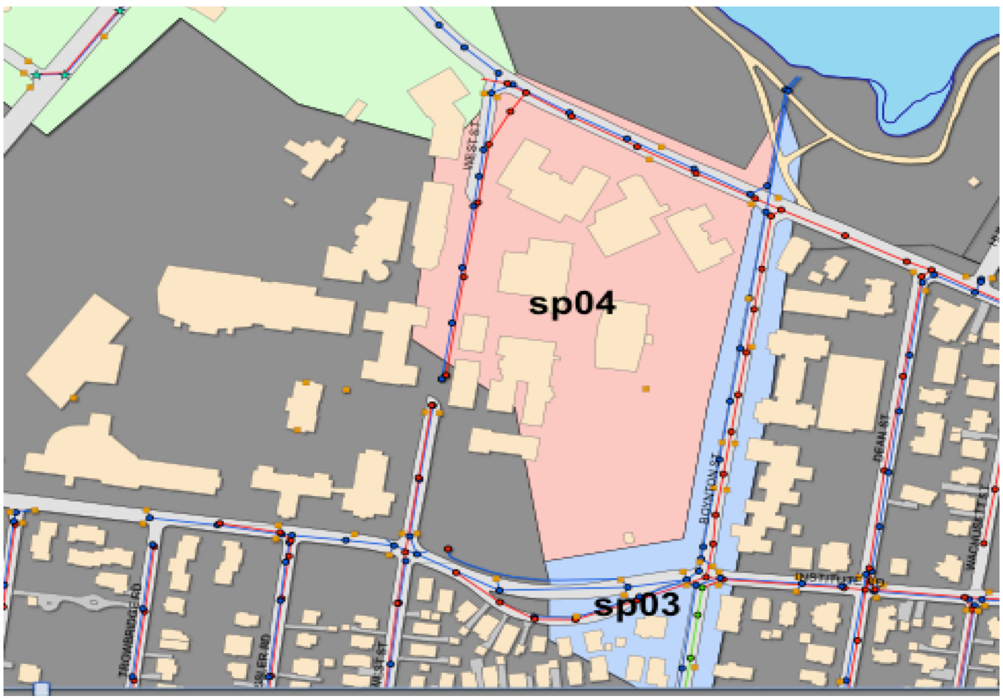


**Figure 5: Map of sp04 Region (City of Worcester, 2008)**

The storm drainage system that WPI water travels through is located under Boynton Street and through the sp03 area, shown in blue. A close up view of storm drain system that the Boynton Parking lot runoff enters is shown in Figure 6.

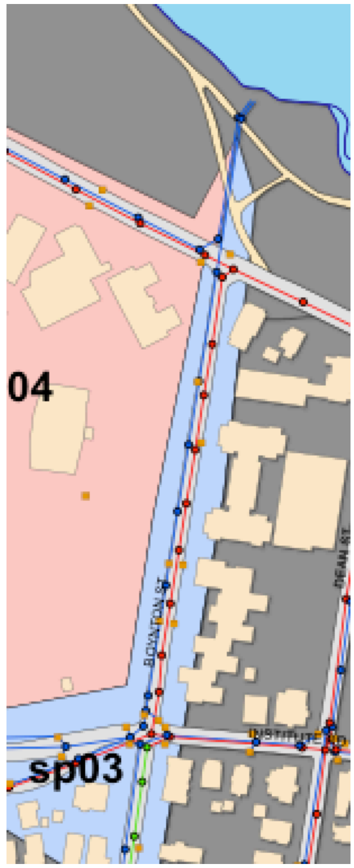


**Figure 6: Sewer System (City of Worcester, 2008)**

Some catch basins were not originally displayed on the GIS map or City of Worcester maps of campus, but areal views of campus were used to plot catch basins on the maps. In Figure 6, the blue line through sp03 is the storm drain system that runoff from the Boynton street parking lot enters. This water then flows into Salisbury Pond.

Some of the runoff that enters this sewer system drains are from surrounding neighborhoods. WPI, therefore, does not have full control over the entire quality or quantity of runoff entering the pond. However, WPI can make an impact by implementing a best management strategy at a priority area (or priority areas) on campus. Priority areas were determined based on location, contours, and near-by catch basins, and feasibility. The locations that could have the biggest area of impact, discussed in the succeeding section, would be large flat areas of land where a lot of runoff is generated.

### 5.2 Priority Area Analysis

The best management suggested for WPI is the design of permeable pavement at a priority area on campus. Priority areas were determined using an objective process. The areas were determined based on biggest area for impact, location, and feasibility. The priority areas for the design of permeable pavement are:

1. Boynton Parking Lot/Library Lot
2. Quadrangle Area
3. Goddard Hall Area and Service Access Road

The area calculated for the library lot impervious surface is 6,200 $m^2$. The second biggest area measured was the Quadrangle with 4,197.7 $m^2$. The third biggest area measured was Goddard Hall and the access road at 1,607 $m^2$. The three pervious areas were compared and analyzed separately. They were analyzed for the impact they would have on runoff reduction with an impervious surface design.

The Library Lot is a large, flat, pervious surface, as seen in Figure 7. Also, the library lot is located at the bottom of a hill on which much of the WPI campus is located. Therefore, this area generates a significant amount of runoff that can be mitigated with permeable pavements.

**Figure 7: GIS Map of Library Lot**

The next largest priority area is the Quadrangle. The Quadrangle is also a flat area, seen in Figure 8. This area, however, is located on top of a hill and will not collect as much runoff as the library lot. There is not a lot of pervious area compared to the Library Lot, and use of permeable pavement at this site will not have a significant impact on runoff.

**Figure 8: GIS Map of Quadrangle**

Goddard Hall Parking Lot and attached surface road, is the least flat land of the three priority areas (Figure 9). Goddard Hall Parking Lot is similar to the quadrangle area. It is located at the top of campus and will not accumulate as much run off as the library parking lot. The service road connects to Goddard Hall and down into the library parking lot. Therefore, this area is least desired for permeable pavement design.

**Figure 9: GIS Map of Goddard Hall Parking Lot**

After determining the Library Lot was the best location to install a permeable pavement design based on feasibility and biggest area of impact, the effectiveness of the design was analyzed.

## 5.3 Rainfall Results

To test the effectiveness of the permeable pavement the Technical Release 55 (TR-55) Method was used. The TR-55 method calculates storm runoff volume, peak rate of discharge, hydrographs, and storage volumes (USDA, 1986). Figure 10 displays the type III rainfall distribution for 0-24 hours.

Type III was used for this area due to TR-55 classification. Type III classification is used for Atlantic Coastal areas where tropical storms bring large 24-hour rainfall amounts (USDA, 1986).

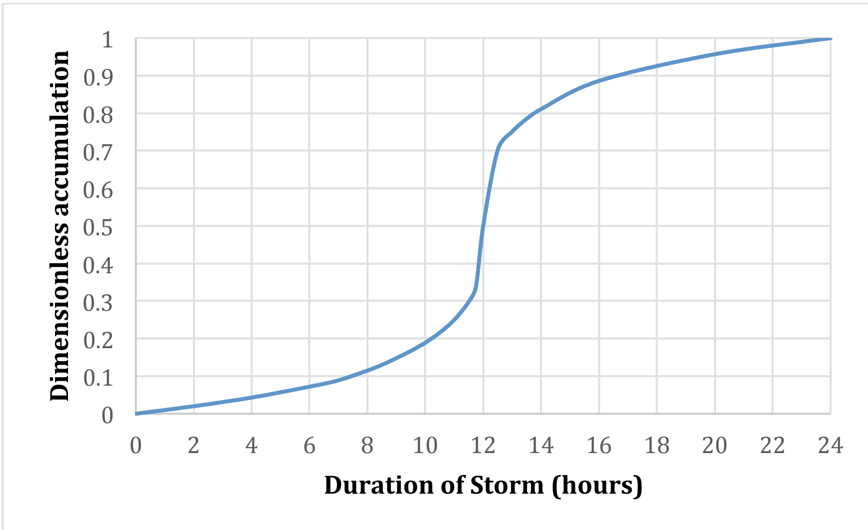


**Figure 10: SCS Type III Rainfall Distribution**

Figure 10 shows that the peak rainfall is at 12 hours. The distribution for WPI follows this distribution and will have similar patterns for rainfall.

Values were taken from the excel document in appendix D and figures 11 and 12 were created to compare infiltrate amounts of permeable pavement versus conventional pavement. Figure 11 displays the rainfall infiltraion for a 10 year storm with conventional pavement. The amount infiltrated into conventional pavement is displayed by the orange dotted line. This infiltration would be zero for hours 0-24 and 100% of the rainfall would result running off.

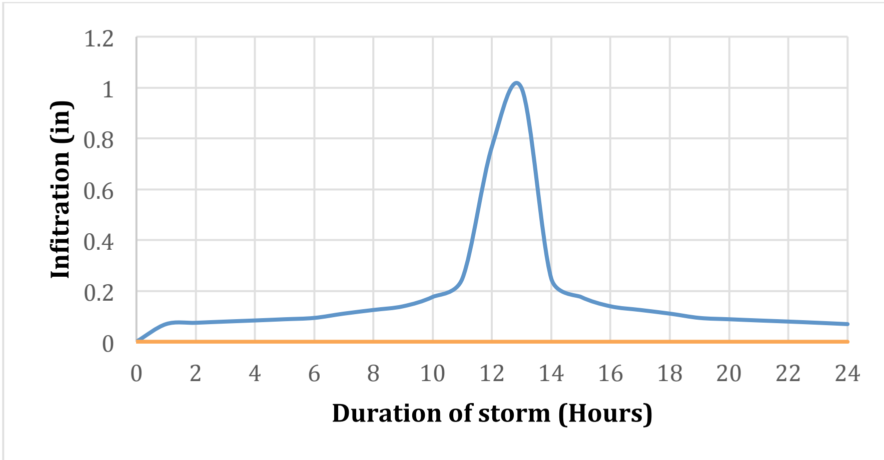


**Figure 11: 10- year storm Rainfall Infiltration with Conventional Pavement**

Figure 12 displays the rainfall infiltration for a 10 year storm with a permeable pavement design. 12 hours after the start of the storm, there is a peak in rainfall. With the permeable pavement, almost all of the runoff will be infiltrated and there will be very little runoff. The blue line in the graph displays the rainfall distribution over 24 hours. All rainfall below the orange dotted line at 0.4m is infiltrated straight into the ground. All rainfall below the red dotted line at 1.0 infiltrated is the theoretical infiltration through the pavement.

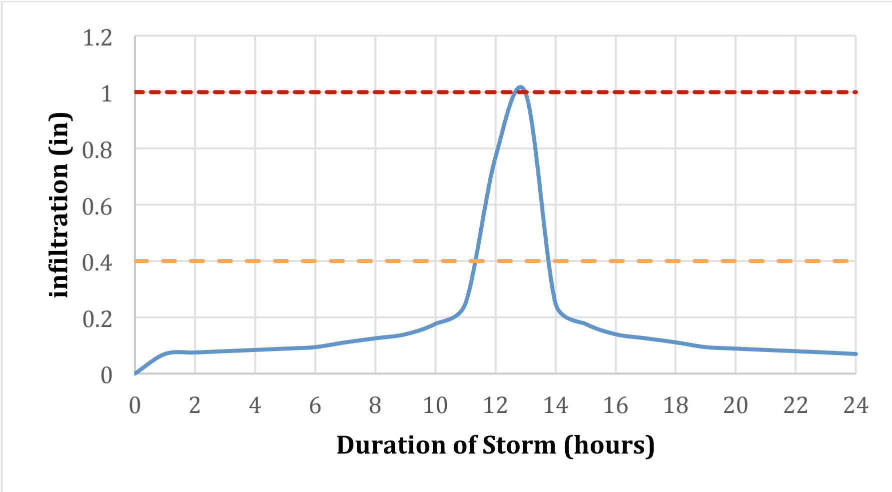


**Figure 12: 10-year storm Rainfall Infiltration with Permeable Pavement**

When comparing Figures 11 and 12, it is clear that with a permeable pavement design, a significant amount of stormwater would be infiltrated opposed to exiting as runoff. The only time when the permeable pavement design does not infiltrate all stormwater is during the peak hour. The peak has 1.01 inches of rainfall and the pavement can infiltrate 1.0 inches. Therefore, even during the peak hour, only 0.01 inches will result in runoff.

Table 2 displays the amounts of runoff that is infiltrated and what will result in being stormwater runoff for different year storms. Also displayed is the amount of runoff stored in the storage area of the pavement design. For the ten year storm, there will be approximately 4.4 meters of runoff and about 3.74 meters will be infiltrated into the pavement. Only approximately 0.6 meters will runoff and enter the sewer systems. For conventional pavement design, the amount infiltrated would be 0 m for each year storm. The runoff depth would be the total amount of This is a large decrease in the volume of stormwater runoff entering Salisbury Pond.

**Table 2: Rainfall and Infiltration of Stormwater for Permeable Pavements vs. Conventional Pavement**

| Return Period (year storm) | 1 | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| **Conventional Pavement** | | | | | | | |
| **Depth Rainfall (in)** | 2.47 | 2.95 | 3.68 | 4.35 | 5.43 | 6.42 | 7.6 |
| **Infiltration (in)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Stored water (m)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Runoff Depth (m)** | 2.47 | 2.95 | 3.68 | 4.35 | 5.43 | 6.42 | 7.6 |
| **Permeable Pavement** | | | | | | | |
| **Depth Rainfall (in)** | 2.47 | 2.95 | 3.68 | 4.35 | 5.43 | 6.42 | 7.6 |
| **Infiltration (in)** | 2.24 | 2.64 | 2.32 | 3.74 | 4.57 | 5.29 | 6.15 |
| **Stored water (m)** | 0.20 | 0.25 | 0.32 | 0.39 | 0.54 | 0.69 | 0.92 |
| **Runoff Depth (m)** | 0.23 | 0.31 | 0.452 | 0.61 | 0.86 | 1.13 | 1.45 |

These values were calculated by taking rainfall intensities for different return periods and distributed them on a type III intensity hydrograph. The hydrograph displayed intensities in units of inches per hour. The runoff was calculated by subtracting the infiltration rate of the pavement from rainfall intensity. All values were entered into an excel document, found in Appendix D. The values shown in both tables were taken from the excel document.

### 5.4 Permeable Pavement Design

For this best management practice, the effectiveness of the permeable pavement on the library lot was analyzed, cost was evaluated for test plot and full design, and final recommendations are made.

### 5.4.1 Priority area for design development

Out of all three priority areas. Boynton Parking Lot, Goddard Hall Parking Lot, and Quadrangle, it was determined that the Library Lot was most feasible. Unlike the two other areas, the pavement in the library lot has not been redone in many years. It is in extremely poor condition and with the many renovations that have been underway at WPI, it is most likely that this would be the most feasible option to begin construction and design on. For the design it is recommended to replace the Library Lot (67,518 $ft^2$) with permeable pavement.

The design of the library lot has a significant effect on the runoff volume of the entire campus. For different year storms, the runoff volume for the entire sp04 region with existing conditions was calculated using TR-55 method. The runoff volume from the sp04 region was calculated again with the installation of permeable pavements in the library lot. These runoff values were calculated by subtracting the volume infiltrated through permeable pavements.

The values for different year storms and percent reduction for each are shown in Table 3. For a 10-year storm, the volume runoff in the sp04 region, prior to the permeable pavement design, was 161,480 $ft^3$. After the permeable pavement design, the volume runoff for sp04 region would be 140,998 $ft^3$. The percent reduction can be found using equation $\frac{(Vr-Vf)}{Vr}$. The percent reduction for the 10-yr storm is 12.68%.

**Table 3: Percent Reduction for sp04 region with permeable pavement design**

| Storm Return Period | Runoff over sp04 with conventional pavement (existing conditions) | Runoff over sp04 with Permeable Pavement in Library Lot | % Reduction |
|---|---|---|---|
| 1 | 68643.3 $ft^3$ | 56,375.9 $ft^3$ | **17.87 %** |
| 2 | 91711.95 $ft^3$ | 77,254.0 $ft^3$ | **15.76 %** |
| 5 | 127,158.9 $ft^3$ | 109,469.8 $ft^3$ | **13.91 %** |
| 10 | 161,480.6 $ft^3$ | 140,998.4 $ft^3$ | **12.68 %** |
| 25 | 218,308.2 $ft^3$ | 193,280.6 $ft^3$ | **11.46 %** |
| 50 | 271,197.3 $ft^3$ | 242,226.6 $ft^3$ | **10.68 %** |
| 100 | 334,776.8 $ft^3$ | 301,096.3 $ft^3$ | **10.06 %** |

This permeable pavement design would significantly reduce the volume runoff from WPI campus. There are two types of permeable pavement that can be used for design to reduce runoff.

### 5.4.2 Permeable pavement selection

For the full pavement there were two alternatives considered against conventional pavement: Pervious Asphalt, Pervious Concrete. Conventional pavement is approximately 20% less expensive than permeable pavements (Huffman, 2008). Conventional pavement will not reduce the amount of runoff and therefore has no environmental impacts. Pervious asphalt is less expensive but is less durable, for smaller areas, and shorter lifespan. Pervious concrete is a more expensive option to pervious asphalt but is more durable, has a longer lifespan, and ideal for parking lot usage. Both pervious concrete and pervious asphalt have environmental impacts and will reduce runoff volume.

The purpose of this design is to reduce stormwater runoff and the concrete design in figure 13 will meet this goal. Figure 13 shows a cross section view of the pavement design that will meets the goal

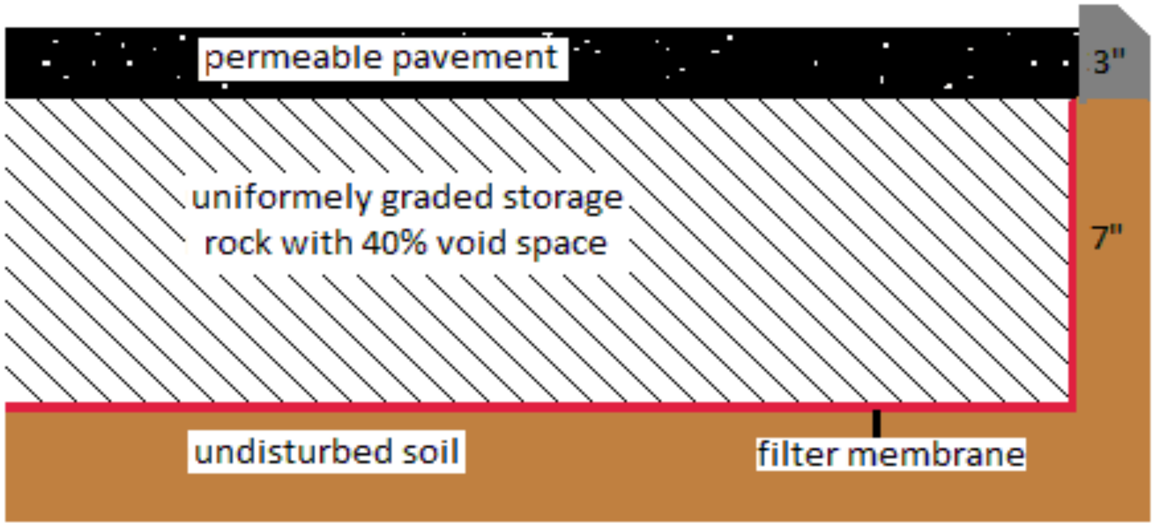


**Figure 13: Permeable Pavement Design**

The first layer would be a permeable pavement with interconnected voids to allow stormwater to flow through. The stormwater that flows through would then enter the uniformly graded storage rock with 40% void space. This space would collect sediments and store water. The water would then flow through a filter membrane, where sediments would be blocked before entering the undisturbed soil. Filter membranes keep solids and sediments in the uniformly graded storage rock. Before implementing the full design of this permeable pavement, a test plot can be used to test effectiveness.

### 5.4.3 Test Plot Design and monitoring approaches

For each alternative, it is recommended that a test plot should be developed before pavement of the full lot to test for effectiveness of the permeable pavement.

For the test plot design at the Boynton Street parking lot, the area will cover 1,000 $ft^2$. The parking lot has a side section, adjacent to the main area of the lot. This side section will serve as an ideal location for a test plot. The area can be seen in Figure 14.


**Figure 14: Boynton Parking Lot and Test Plot Area**

The pavement of the full lot, with either pervious concrete or pervious asphalt, is a costly project. Before implementing this best management practice, the test plot can serve as a study to test effectiveness, durability, and construction and installation practicability. For this test plot area of 1,000 ft the cost of both pervious concrete and pervious asphalt for two years of monitoring is displayed in table 4. Calculations for the cost values can be found in Appendix C.

**Table 4: Cost Analysis for Test Plot**

| Alternative Pavement for Test Plot | Design Area | Life Span | Total Cost for 2 years |
|---|---|---|---|
| Test Plot Pervious Concrete | 1,000 $ft^2$ | 2 yrs | $24,000 |
| Test Plot Pervious Asphalt | 1,000 $ft^2$ | 2 years | $16,100 |

The test plot design should have a monitoring well for the testing of effectiveness. Monitoring wells and ground water sampling collections were developed with the intention of obtaining a representative sample of water from an aquifer. Monitoring wells minimize the potential for the introduction of contaminants into the ground.

When installing a monitoring well soil borings may be made or rock-core samples may be collected to determine the geology and mechanics of the site. The geology and mechanics are important to know for different purposes of the monitoring well. Some purposes for designing a monitoring well include:

- Measuring the elevation of the water table
- Measuring a potentiometric water level within an aquifer
- Collecting a water sample for chemical analysis
- Collecting a sample of nonaqueous phase liquid that is less dense than water
- Collecting a sample of nonaqueous phase liquid that is less dense than water

- Collecting a sample of nonaqueous phase liquid that is more dense than water
- Testing the permeability of an aquifer or aquiclude
- Providing access for geophysical instruments
- Collecting a sample of soil gas

Each use listed above has a different design. Some designs will have different materials, diameters, screens, lengths, depths, and filters. For the design of the proposed monitoring well at WPI, the main reason for installation is to measure the effectiveness of the pervious pavements specifically at the site of the test plot. The necessary design components for this well are: well casing, well screens, naturally developed well, and protective casing.

For any investment made, it is crucial to take preventative measures to increase the life span and effectiveness of the investment. For the test plot proposed for design, the location of the monitoring well will be placed underground.  After using the test plot area and monitoring well, the Boynton Street Parking lot pavement design will be implemented.

### 5.4.4 Boynton Street Parking Lot Permeable Pavement design

For the library lot, two types of permeable pavement were considered for the design: pervious concrete and pervious asphalt. Each option was compared against the other as well as to conventional pavement. The average cost for 15 years of concrete and asphalt are displayed in table 5.2. The costs include maintenance, material, installation and construction costs. The full calculations can be found in Appendix C.

**Table 5: Cost Analysis for Boynton Lot**

| Alternative Pavement for Boynton Lot | Design Area | Life Span | Total Cost for 15 years |
|---|---|---|---|
| Pervious Concrete | 67,518 $ft^2$ | 20-30 years | $1,500,400 |
| Pervious Asphalt | 67,518 $ft^2$ | 15-20 years | $1,063,400 |

For the design of conventional pavement, would be about $1,100,000. The different is not that much for this project. The benefits for pervious pavement outweigh the cost. The typical cost for conventional pavement is about 20% less than the permeable pavement options. For a large area the 20% increase can be a significant amount of money. However, for some purposes the permeable pavement benefits outweigh the cost. Future costs, with a 3.5% interest rate, and present worth cost were calculated and presented in Table 6. Full calculations can be found in Appendix C.

**Table 6: Engineering Cost Analysis**

| Cost analysis | Pervious Concrete | Pervious Asphalt |
|---|---|---|
| Present Value | $1,500,400 | $1,063,400 |
| Future Worth | $31,058,280 | $16,509,280 |

The future worth for the pervious concrete is approximately double the worth of the pervious asphalt. Although it was $500,000 more at present value, the future worth is about $14 million more.

This best management practice and design can significantly reduce the runoff volume from WPI. One of the three major inlets entering Salisbury Pond consists of mainly runoff coming from just WPI. The design of the pavement will significantly improve the water quantity and quality from that one inlet.

## 6.0 Conclusions and Recommendations

For this project, a stormwater management plan was created to reduce stormwater runoff draining from WPI's campus into Salisbury pond. The plan consists of education, illicit discharge detection, construction and post-construction site control measures, and a pollution prevention plan with best management practices. The best management practice that would effectively meet the needs of reducing runoff volume to the greatest extent possible is the design of a permeable pavement in the Boynton Parking Lot. This design of a 67,518 $ft^2$ permeable pavement lot would result in infiltration almost all of the stormwater that flows onto the parking lot, and in turn would reduce the volume of runoff entering the pond.

For example, for a 10-year storm, with a permeable pavement lot in place, the volume of runoff that would infiltrate is 3.74m of the total 4.35m that accumulates, resulting in 0.61 m of runoff that would flow to the pond. Table 3 displays the percent reduction of the entire sp04 region with the installation of the permeable pavement design. With the permeable pavement design for a 10-year storm, the volume runoff would be reduced 12.68% for the sp04 region of campus.

If WPI implements a stormwater management plan and implements this proposed best management practice, the quantity and quality of runoff coming from the campus will be greatly improved. The scope of this project included focus on the sp04 region. With future research it is recommended that best management practices be proposed for the areas of campus outside of this region, including Gateway Park. The sp04 encompasses a large percentage of campus but there are other areas of campus that drain into surrounding water bodies. With additional BMPs made in other areas of campus, the stormwater runoff volume can continue to be reduced, as seen with the design proposed for this project.

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# Appendix A: TR-55 Method

**TR-55 Method**

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

$$S = \frac{1000}{CN} - 10$$

Q= runoff
P=precipitation
$I_a$=Initial abstraction
S= Retention

**Soil Types:**

Sp01= 2/5 C, 2/5 D, 1/5 B
Sp02= 4/5C, 1/5B
Sp03= 100% C
Sp04= 50% A, 25% B, 25%C
Parking Lot 80% B, 20%C
Sp05= 60% C, 20% B, 20% A

**Impervious %**
Sp01: >75% grassy, ~0.55 acre lots
Sp02: >75% grassy, ~0.55 acre lots
Sp03: 61% grassy
Sp04: 59% grassy
Sp05: 50-73% grassy

Sp04 Parking Lot
1.55 acres
1.24 B
0.31 C

Total:
15.81 acres
4.25 buildings
2.72 roads/parking lots
1.30 walkways
7.54 “good” = 5.03 C, 2.51 A

Sp01: Total= 151.90
Sp02: Total= 11.31
Sp03: Total= 63.65

**Sp04**:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

P=2.95
Ia= 0.32
CN=86
S=1.627

Q=1.63”

$$T_t = \frac{0.007(nL)^{0.08}}{{P_2}^{0.5} S^{0.4}}$$

$T_t$= travel time
n= mannings =0.011
L=Flow Length
$P_2$= 2year fall=2.95
S=Slope

$Q_p$=$(q_u)^2$($A_m$)($F_p$)(Q)

$Q_p$= Peak Runoff
$q_u$= Unit Peak Discharge (csm/inches)
$A_m$ = Drainage Area
$F_p$ = Wetlands
Q=Runoff

$Q_p$=(750csm/in$^2$)(0.0239mi$^2$)(1)(1.63in)=29.2 CF/S
(1.63)(15.3 acres)= 2563m$^3$ runoff

**For a 100 year storm:**

$$Q = \frac{(7.6 - 0.32)^2}{(7.6 - 0.32) + 1.627}$$

Q=5.95” runoff

Amount of runoff for 100 year storm 33,759 ft$^3$

# Appendix B: Retention of Priority Area Lots

**Library Lot with permeable pavements over 7-hour period**

A= 6200 $m^2$ = 67,518 $ft^2$

(0.0833 ft/hr)( 67,518 $ft^2$)= 5,626.5 $ft^3$/hr

Retention:
(5,626.5 $ft^3$/hr) (7 hr)= ***39,385.5 $ft^3$(***

39,385.5 > 33,759 so the parking lot with permeable pavements can retain runoff of a 100 year storm.

**Quad with permeable pavements over 7 hour period**

A= 4197.7 $m^2$ = 45,184 $ft^2$

(0.0833 ft/hr)( 45,184 $ft^2$)= 3,763.83 $ft^3$/hr

Retention:
(3,763.83 $ft^3$/hr) (7 hr)= ***26,346.79 $ft^3$***

**Goddard with permeable pavements over 7 hour period**

A= 1670.14 $m^2$ = 17,977 $ft^2$

(0.0833 ft/hr)( 17,977 $ft^2$)= 1,497.48 $ft^3$/hr

Retention:
(1,497.48 $ft^3$/hr) (7 hr)= ***10,482.40 $ft^3$***

# Appendix C: Design Properties

## Pervious Concrete

**Scale:** Small and large scale paving
**Pavement Thickness:** 5-8 inches
**Bedding Layer:** none
**Construction Properties:** Cast in place, seven day cure, must be covered
**Design Permeability:** 10 ft/day
**Construction Cost:** $2.00- $6.50/ sq.ft
**Minimum Batch Size:** 500 sq.ft
**Longevity:** 20-30 years
**Traffic Bearing:** Can handle all traffic loads
**Surface Clogging:** Replace paved areas or install drop inlet
**Main Uses:** driveways, parking areas, sidewalks, patios, pool decking

**Design Cost for Library Lot:**
**High Range-**
Construction Cost: ($6.50/sqft)(67518 sqft)= $438,867
Pavement Cost: ($8.00/sqft)(67518 sqft)= $540,144
**Total Cost High Range:** $979,011

**Low Range-**
Construction Cost: ($2.00/sqft) (67518 sqft)= $135,036
Pavement Cost: ($6.75/sqft) (67518 sqft)= $455,747
**Total Cost Low Range:** $590,782

**Average Cost: $784,896**

**Additional Costs**
**$450 for maintenance/year – for 15 years ($6750)**
**Average Installation Cost: $10.50/ sqft**

**Total Average cost for 15 years $1,500,400**

## Pervious Asphalt

**Scale:** Small and large scale paving
**Pavement Thickness:** 3-4 inches
**Bedding Layer:** 2 inches of No. 57 stone
**Construction Properties:** Cast in place, 24 hour cure
**Design Permeability:** 6 ft/day
**Construction Cost:** $0.50 - $1.00 / sqft
**Minimum Batch Size:** None
**Longevity:** 15-20 years
**Traffic Bearing:** --
**Surface Clogging:** Replace paved areas or install drop inlet
**Main Uses:** driveways, parking areas

**Design Cost for Library Lot:**
**High Range-**
Construction Cost: ($1.00/sqft) (67518 sqft)= $67,518
Pavement Cost: ($5.40/sqft) (67518 sqft)= $364,597
**Total Cost High Range:** $432,115

**Low Range-**
Construction Cost: ($0.50/sqft) (67518 sqft)= $33,759
Pavement Cost: ($3.40/sqft) (67518 sqft)= $229,561
**Total Cost High Range:** $263,320

**Average Cost: $347,717**

**Additional Costs**
**$450 for maintenance/year – for 15 years ($6750)**
**Average Installation Cost: $10.50/ sqft**

**Total Average cost for 15 years $1,063,406**

## Test Plot Asphalt Cost:
**Area: 1000 sqft**

**Design Cost for Library Lot:**
**High Range-**
Construction Cost:  ($1.00/sqft) (1000 sqft)= $1,000
Pavement Cost: ($5.40/sqft) (1000 sqft)=  $5400
**Total Cost High Range:** $6400

**Low Range-**
Construction Cost:  ($0.50/sqft) (1000 sqft)= $500
Pavement Cost: ($3.40/sqft) (1000 sqft)=  $3400
**Total Cost High Range:** $3900

**Average Cost: $5150**

**Additional Costs**
**$450 for maintenance/year – for 2 years ($900)**
**Average Installation Cost: $10.50/ sqft**

**Total Average cost for 2 years $16,550**

## Test Plot Concrete Cost:
**Area: 1000 sqft**

**Design Cost for Library Lot:**
**High Range-**
Construction Cost: ($6.50/sqft) (1000 sqft)= $6,500
Pavement Cost: ($8.00/sqft) (1000 sqft)= $8000
**Total Cost High Range:** $14,500

**Low Range-**
Construction Cost: ($2.00/sqft) (1000 sqft)= $2,000
Pavement Cost: ($6.75/sqft) (1000 sqft)= $6750
**Total Cost High Range:** $8750

**Average Cost: $11,625**

**Additional Costs**
**$450 for maintenance/year – for 2 years ($900)**
**Average Installation Cost: $10.50/ sqft**

**Total Average cost for 2 years $23,925**

**Compound Interest: Pervious Concrete**
F= Future Value
P= Present Value
I= interest rate
N= number of years

P=**$1,500,400**
i=**3.5%**
n= **20 years**

**F=P(1+i)n**
F=($1,500,400)(1+0.035)(20 yrs)

**F =$31,058,280**

**Compound Interest: Pervious Asphalt**
F= Future Value
P= Present Value
I= interest rate
N= number of years

P=**$1,500,400**
i=**3.5%**
n= **15 years**

**F=P(1+i)n**
F=($1,063,400)(1+0.035)(15 yrs)

**F =$16,509,285**

# Appendix D: Rainfall Data

Workbook 1: Infiltration, volume that enters storage rock, and volume runoff
Workbook 2: Amount infiltration for storm hours 0-24 for 1, 2, 5, 10, 25, 50, and 100 year storms
Workbook 3: Depth Rainfall, infiltration, stored water, and runoff depth for 1, 2, 5, 10, 25, 50, and 100 year storms
Workbook 4: sp04 volume runoff before and after permeable pavement design

## Workbook 1:

| duration | % total rainfall | % at time | Worcester | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 1 year | 2 year | 5 year | 10 year | 25 year |
| 2 | 0.02 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0.043 | 0.023 | 0.0494 | 0.059 | 0.0736 | 0.0868 | 0.1086 |
| 6 | 0.072 | 0.029 | 0.05681 | 0.06785 | 0.08464 | 0.09982 | 0.12489 |
| 7 | 0.089 | 0.017 | 0.07163 | 0.08555 | 0.10672 | 0.12586 | 0.15747 |
| 8 | 0.115 | 0.026 | 0.04199 | 0.05015 | 0.06256 | 0.07378 | 0.09231 |
| 8.5 | 0.13 | 0.015 | 0.06422 | 0.0767 | 0.09568 | 0.11284 | 0.14118 |
| 9 | 0.148 | 0.018 | 0.03705 | 0.04425 | 0.0552 | 0.0651 | 0.08145 |
| 9.5 | 0.167 | 0.019 | 0.04446 | 0.0531 | 0.06624 | 0.07812 | 0.09774 |
| 9.75 | 0.178 | 0.011 | 0.04693 | 0.05605 | 0.06992 | 0.08246 | 0.10317 |
| 10 | 0.189 | 0.011 | 0.02717 | 0.03245 | 0.04048 | 0.04774 | 0.05973 |
| 10.5 | 0.216 | 0.027 | 0.02717 | 0.03245 | 0.04048 | 0.04774 | 0.05973 |
| 11 | 0.25 | 0.034 | 0.06669 | 0.07965 | 0.09936 | 0.11718 | 0.14661 |
| 11.5 | 0.298 | 0.048 | 0.08398 | 0.1003 | 0.12512 | 0.14756 | 0.18462 |
| 11.75 | 0.339 | 0.041 | 0.11856 | 0.1416 | 0.17664 | 0.20832 | 0.26064 |
| 12 | 0.5 | 0.161 | 0.10127 | 0.12095 | 0.15088 | 0.17794 | 0.22263 |
| 12.5 | 0.702 | 0.202 | 0.39767 | 0.47495 | 0.59248 | 0.69874 | 0.87423 |
| 13 | 0.751 | 0.049 | 0.49894 | 0.5959 | 0.74336 | 0.87668 | 1.09686 |
| 13.5 | 0.785 | 0.034 | 0.12103 | 0.14455 | 0.18032 | 0.21266 | 0.26607 |
| 14 | 0.811 | 0.026 | 0.08398 | 0.1003 | 0.12512 | 0.14756 | 0.18462 |
| 16 | 0.886 | 0.075 | 0.06422 | 0.0767 | 0.09568 | 0.11284 | 0.14118 |
| 20 | 0.957 | 0.071 | 0.18525 | 0.22125 | 0.276 | 0.3255 | 0.40725 |
| 24 | 1 | 0.043 | 0.17537 | 0.20945 | 0.26128 | 0.30814 | 0.38553 |
| | | 1 | 0.10621 | 0.12685 | 0.15824 | 0.18662 | 0.23349 |
| | | | 2.47 | 2.95 | 3.68 | 4.35 | 5.43 |

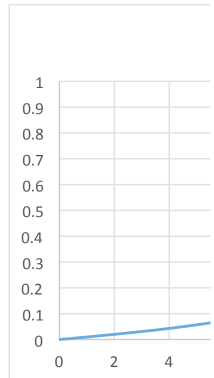
| | | EVERYTHING NOT DIRECTLY INFILTRATED | | | | |
|---|---|---|---|---|---|---|
| TIME | YR STRM | 1 | 2 | 5 | 10 | 25 |
| 0 | | 0 | 0 | 0 | 0 | 0 |
| 2 | | 0 | 0 | 0 | 0 | 0 |
| 4 | | 0 | 0 | 0 | 0 | 0 |
| 0 | | 0 | 0 | 0 | 0 | 0 |
| 7 | | 0 | 0 | 0 | 0 | 0 |
| 8 | | 0 | 0 | 0 | 0 | 0 |
| 8.5 | | 0 | 0 | 0 | 0 | 0 |
| 9 | | 0 | 0 | 0 | 0 | 0 |
| 9.5 | | 0 | 0 | 0 | 0 | 0 |
| 9.75 | | 0 | 0 | 0 | 0 | 0 |
| 10 | | 0 | 0 | 0 | 0 | 0 |
| 10.5 | | 0 | 0 | 0 | 0 | 0 |
| 11 | | 0 | 0 | 0 | 0 | 0 |
| 11.5 | | 0 | 0 | 0 | 0 | 0 |
| 11.75 | | 0 | 0 | 0 | 0 | 0 |
| 12 | | 0 | 0.07495 | 0.19248 | 0.29874 | 0.47423 |
| 12.5 | | 0.09894 | 0.1959 | 0.34336 | 0.47668 | 0.69686 |
| 13 | | 0 | 0 | 0 | 0 | 0 |
| 13.5 | | 0 | 0 | 0 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 14 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0.00725 |
| 20 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 |

EVERYTHING STRAIGHT TO RUNOFF

| TIME | YR STRM | 1 | 2 | 5 | 10 | 25 |
|---|---|---|---|---|---|---|
| 0 | | 0 | 0 | 0 | 0 | 0 |
| 2 | | 0 | 0 | 0 | 0 | 0 |
| 4 | | 0 | 0 | 0 | 0 | 0 |
| 6 | | 0 | 0 | 0 | 0 | 0 |
| 7 | | 0 | 0 | 0 | 0 | 0 |
| 8 | | 0 | 0 | 0 | 0 | 0 |
| 8.5 | | 0 | 0 | 0 | 0 | 0 |
| 9 | | 0 | 0 | 0 | 0 | 0 |
| 9.5 | | 0 | 0 | 0 | 0 | 0 |
| 9.75 | | 0 | 0 | 0 | 0 | 0 |
| 10 | | 0 | 0 | 0 | 0 | 0 |
| 10.5 | | 0 | 0 | 0 | 0 | 0 |
| 11 | | 0 | 0 | 0 | 0 | 0 |
| 11.5 | | 0 | 0 | 0 | 0 | 0 |
| 11.75 | | 0 | 0 | 0 | 0 | 0 |
| 12 | | 0 | 0 | 0 | 0 | 0 |
| 12.5 | | 0 | 0 | 0 | 0 | 0.09686 |
| 13 | | 0 | 0 | 0 | 0 | 0 |
| 13.5 | | 0 | 0 | 0 | 0 | 0 |
| 14 | | 0 | 0 | 0 | 0 | 0 |
| 16 | | 0 | 0 | 0 | 0 | 0 |
| 20 | | 0 | 0 | 0 | 0 | 0 |
| 24 | | 0 | 0 | 0 | 0 | 0 |
| | TOTAL RUNOFF | 0 | 0 | 0 | 0 | 0.09686 |

| 50 year | 100 year | straight through | infiltrated |
|---|---|---|---|
| 0 | 0 | 0.4 | 1 |
| 0.1284 | 0.152 | 0.4 | 1 |
| 0.14766 | 0.1748 | 0.4 | 1 |
| 0.18618 | 0.2204 | 0.4 | 1 |
| 0.10914 | 0.1292 | 0.4 | 1 |
| 0.16692 | 0.1976 | 0.4 | 1 |
| 0.0963 | 0.114 | 0.4 | 1 |
| 0.11556 | 0.1368 | 0.4 | 1 |
| 0.12198 | 0.1444 | 0.4 | 1 |
| 0.07062 | 0.0836 | 0.4 | 1 |
| 0.07062 | 0.0836 | 0.4 | 1 |
| 0.17334 | 0.2052 | 0.4 | 1 |
| 0.21828 | 0.2584 | 0.4 | 1 |
| 0.30816 | 0.3648 | 0.4 | 1 |
| 0.26322 | 0.3116 | 0.4 | 1 |
| 1.03362 | 1.2236 | 0.4 | 1 |
| 1.29684 | 1.5352 | 0.4 | 1 |
| 0.31458 | 0.3724 | 0.4 | 1 |
| 0.21828 | 0.2584 | 0.4 | 1 |
| 0.16692 | 0.1976 | 0.4 | 1 |
| 0.4815 | 0.57 | 0.4 | 1 |
| 0.45582 | 0.5396 | 0.4 | 1 |
| 0.27606 | 0.3268 | 0.4 | 1 |
| 6.42 | 7.6 | | |

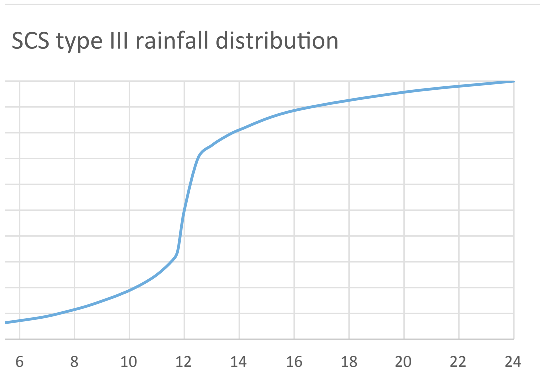



| | | | | EVERYTHING INTO STORAGE | | |
|---|---|---|---|---|---|---|
| 50 | 100 | TIME | YR STRM | 1 | 2 | 5 |
| 0 | 0 | 0 | | 0 | 0 | 0 |
| 0 | 0 | 2 | | 0 | 0 | 0 |
| 0 | 0 | 4 | | 0 | 0 | 0 |
| 0 | 0 | 6 | | 0 | 0 | 0 |
| 0 | 0 | 7 | | 0 | 0 | 0 |
| 0 | 0 | 8 | | 0 | 0 | 0 |
| 0 | 0 | 8.5 | | 0 | 0 | 0 |
| 0 | 0 | 9 | | 0 | 0 | 0 |
| 0 | 0 | 9.5 | | 0 | 0 | 0 |
| 0 | 0 | 9.75 | | 0 | 0 | 0 |
| 0 | 0 | 10 | | 0 | 0 | 0 |
| 0 | 0 | 10.5 | | 0 | 0 | 0 |
| 0 | 0 | 11 | | 0 | 0 | 0 |
| 0 | 0 | 11.5 | | 0 | 0 | 0 |
| 0 | 0 | 11.75 | | 0 | 0 | 0 |
| 0.63362 | 0.8236 | 12 | | 0 | 0.07495 | 0.19248 |
| 0.89684 | 1.1352 | 12.5 | | 0.09894 | 0.1959 | 0.34336 |
| 0 | 0 | 13 | | 0 | 0 | 0 |
| 0 | 0 | 13.5 | | 0 | 0 | 0 |

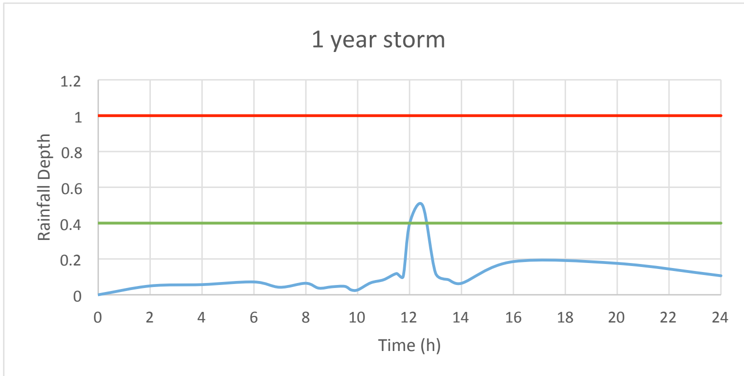
| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 0 | 14 | | 0 | 0 | 0 |
| 0.0815 | 0.17 | 16 | | 0 | 0 | 0 |
| 0.05582 | 0.1396 | 20 | | 0 | 0 | 0 |
| 0 | 0 | 24 | | 0 | 0 | 0 |
| | | TOTAL STORED | | 0.09894 | 0.27085 | 0.53584 |

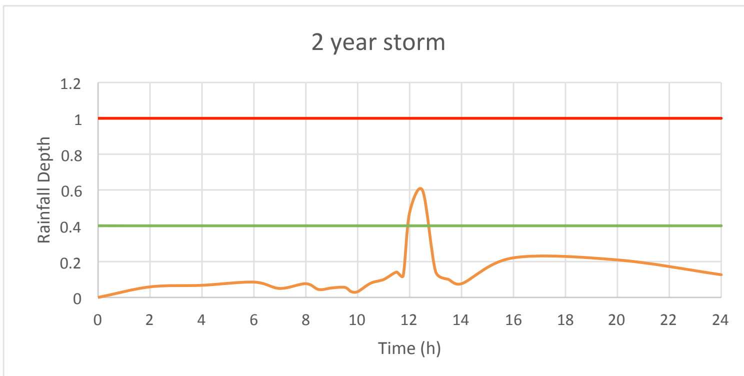
| 50 | 100 |
|---|---|
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0.03362 | 0.2236 |
| 0.29684 | 0.5352 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0.33046 | 0.7588 |

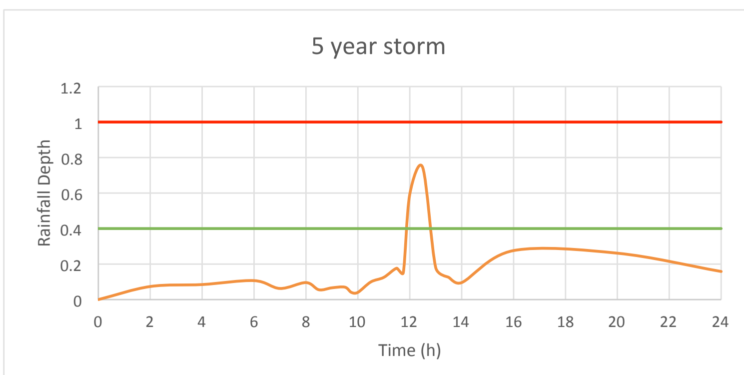
| | | | |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0.00725 | 0.0815 | 0.17 |
| 0 | 0 | 0.05582 | 0.1396 |
| 0 | 0 | 0 | 0 |
| 0.77542 | 1.08148 | 1.33732 | 1.5096 |

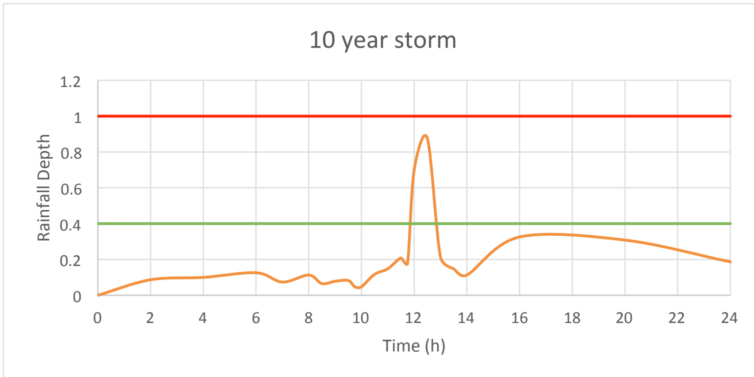


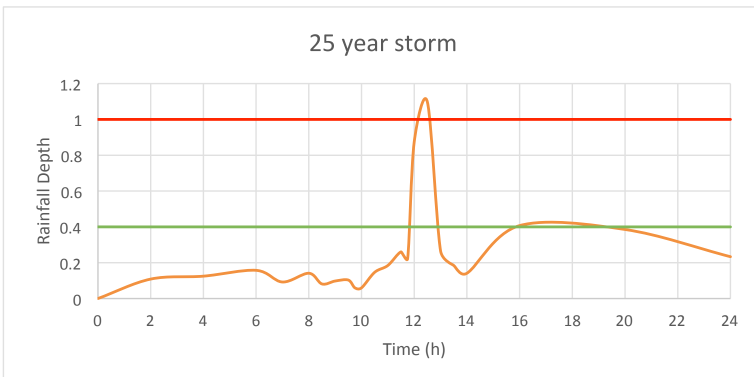

| 10 | 25 | 50 | 100 |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0.29874 | 0.47423 | 0.6 | 0.6 |
| 0.47668 | 0.6 | 0.6 | 0.6 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |

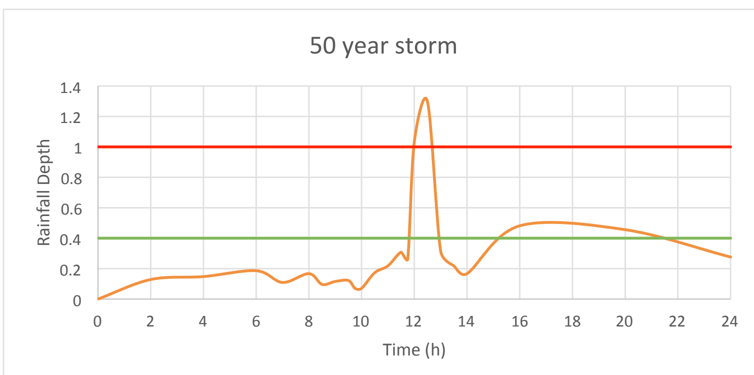

1 year storm
Rainfall Depth
1.2
1
0.8
0.6
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Time (h)

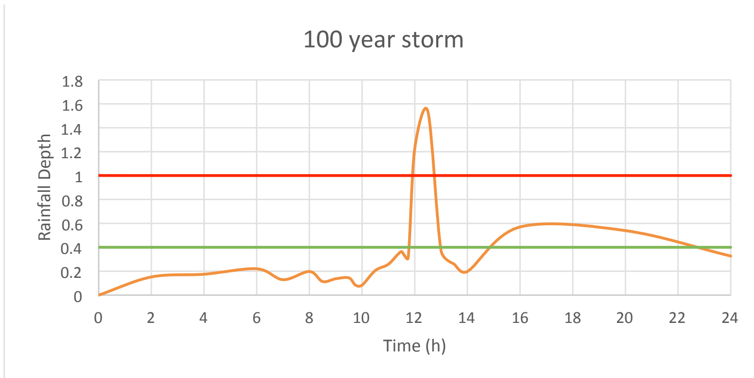

2 year storm
Rainfall Depth
1.2
1
0.8
0.6
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Time (h)


5 year storm
Rainfall Depth
1.2
1
0.8
0.6
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Time (h)


10 year storm
Rainfall Depth
Time (h)
1.2
1
0.8
0.6
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24


25 year storm
Rainfall Depth
Time (h)
1.2
1
0.8
0.6
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24


50 year storm
Rainfall Depth
Time (h)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24


100 year storm
Rainfall Depth
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (h)

Workbook 2:

| Time | 1 | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.8 | 0 | 0 | 0 | 0 | 0.00317 | 0.02198 | 0.0444 |
| 11.9 | 0 | 0 | 0.007824 | 0.027455 | 0.059099 | 0.088106 | 0.12268 |
| 12 | 0.048694 | 0.07759 | 0.121536 | 0.16187 | 0.226886 | 0.286484 | 0.35752 |
| 12.1 | 0.178616 | 0.23276 | 0.315104 | 0.39068 | 0.512504 | 0.624176 | 0.75728 |
| 12.2 | 0 | 0 | 0.007824 | 0.027455 | 0.059099 | 0.088106 | 0.12268 |
| 12.3 | 0 | 0 | 0 | 0 | 0.00317 | 0.02198 | 0.0444 |
| 12.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 13.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 17.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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| 19.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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| 19.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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| 0.108694 | 0.13759 | 0.181536 | 0.22187 | 0.286886 | 0.346484 | 0.41752 | 0.06 |
| 0.238616 | 0.29276 | 0.375104 | 0.45068 | 0.572504 | 0.684176 | 0.81728 | 0.06 |
| 0.032371 | 0.046435 | 0.067824 | 0.087455 | 0.119099 | 0.148106 | 0.18268 | 0.032371 |
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| 0 | 0 | 0 | 0.002354 | 0.010076 | 0.01928 |
| 0 | 0 | 0 | 0.004526 | 0.012644 | 0.02232 |
| 0 | 0 | 0 | 0.006698 | 0.015212 | 0.02536 |
| 0 | 0 | 0 | 0.009413 | 0.018422 | 0.02916 |
| 0 | 0 | 0.001325 | 0.011585 | 0.02099 | 0.0322 |
| 0 | 0.004896 | 0.01307 | 0.026246 | 0.038324 | 0.05272 |
| 0 | 0.007104 | 0.01568 | 0.029504 | 0.042176 | 0.05728 |
| 0.01605 | 0.02992 | 0.04265 | 0.06 | 0.06 | 0.06 |
| 0.046435 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 0.046435 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 0.01605 | 0.02992 | 0.04265 | 0.06 | 0.06 | 0.06 |
| 0 | 0.007104 | 0.01568 | 0.029504 | 0.042176 | 0.05728 |
| 0 | 0.004896 | 0.01307 | 0.026246 | 0.038324 | 0.05272 |
| 0 | 0 | 0.001325 | 0.011585 | 0.02099 | 0.0322 |
| 0 | 0 | 0 | 0.009413 | 0.018422 | 0.02916 |
| 0 | 0 | 0 | 0.006698 | 0.015212 | 0.02536 |
| 0 | 0 | 0 | 0.004526 | 0.012644 | 0.02232 |
| 0 | 0 | 0 | 0.002354 | 0.010076 | 0.01928 |
| 0 | 0 | 0 | 0 | 0.00494 | 0.0132 |
| 0 | 0 | 0 | 0 | 0.003014 | 0.01092 |
| 0 | 0 | 0 | 0 | 0.001088 | 0.00864 |

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| 0.24497 | 0.32384 | 0.38545 | 0.540652 | 0.693772 | 0.9236 |

## Workbook 3:

| Time | T P | Delta P | Yr Storm | 1 | 2 | 5 |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | P Total | 2.47 | 2.95 | 3.68 |
| 0.1 | 0.0016 | 0.0016 | | 0 | 0 | 0 |
| 0.2 | 0.0031 | 0.0015 | | 0.003952 | 0.00472 | 0.005888 |
| 0.3 | 0.0047 | 0.0016 | | 0.003705 | 0.004425 | 0.00552 |
| 0.4 | 0.0063 | 0.0016 | | 0.003952 | 0.00472 | 0.005888 |
| 0.5 | 0.0079 | 0.0016 | | 0.003952 | 0.00472 | 0.005888 |
| 0.6 | 0.0095 | 0.0016 | | 0.003952 | 0.00472 | 0.005888 |
| 0.7 | 0.0111 | 0.0016 | | 0.003952 | 0.00472 | 0.005888 |
| 0.8 | 0.0127 | 0.0016 | | 0.003952 | 0.00472 | 0.005888 |
| 0.9 | 0.0144 | 0.0017 | | 0.003952 | 0.00472 | 0.005888 |
| 1 | 0.016 | 0.0016 | | 0.004199 | 0.005015 | 0.006256 |
| 1.1 | 0.0177 | 0.0017 | | 0.003952 | 0.00472 | 0.005888 |
| 1.2 | 0.0194 | 0.0017 | | 0.004199 | 0.005015 | 0.006256 |
| 1.3 | 0.0211 | 0.0017 | | 0.004199 | 0.005015 | 0.006256 |
| 1.4 | 0.0228 | 0.0017 | | 0.004199 | 0.005015 | 0.006256 |
| 1.5 | 0.0245 | 0.0017 | | 0.004199 | 0.005015 | 0.006256 |
| 1.6 | 0.0262 | 0.0017 | | 0.004199 | 0.005015 | 0.006256 |
| 1.7 | 0.0279 | 0.0017 | | 0.004199 | 0.005015 | 0.006256 |
| 1.8 | 0.0297 | 0.0018 | | 0.004199 | 0.005015 | 0.006256 |
| 1.9 | 0.0314 | 0.0017 | | 0.004446 | 0.00531 | 0.006624 |
| 2 | 0.0332 | 0.0018 | | 0.004199 | 0.005015 | 0.006256 |
| 2.1 | 0.035 | 0.0018 | | 0.004446 | 0.00531 | 0.006624 |
| 2.2 | 0.0368 | 0.0018 | | 0.004446 | 0.00531 | 0.006624 |
| 2.3 | 0.0386 | 0.0018 | | 0.004446 | 0.00531 | 0.006624 |
| 2.4 | 0.0404 | 0.0018 | | 0.004446 | 0.00531 | 0.006624 |
| 2.5 | 0.0422 | 0.0018 | | 0.004446 | 0.00531 | 0.006624 |
| 2.6 | 0.044 | 0.0018 | | 0.004446 | 0.00531 | 0.006624 |
| 2.7 | 0.0459 | 0.0019 | | 0.004446 | 0.00531 | 0.006624 |
| 2.8 | 0.0477 | 0.0018 | | 0.004693 | 0.005605 | 0.006992 |
| 2.9 | 0.0496 | 0.0019 | | 0.004446 | 0.00531 | 0.006624 |
| 3 | 0.0515 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.1 | 0.0534 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.2 | 0.0553 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.3 | 0.0572 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.4 | 0.0591 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.5 | 0.061 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.6 | 0.0629 | 0.0019 | | 0.004693 | 0.005605 | 0.006992 |
| 3.7 | 0.0649 | 0.002 | | 0.004693 | 0.005605 | 0.006992 |
| 3.8 | 0.0668 | 0.0019 | | 0.00494 | 0.0059 | 0.00736 |
| 3.9 | 0.0688 | 0.002 | | 0.004693 | 0.005605 | 0.006992 |
| 4 | 0.0708 | 0.002 | | 0.00494 | 0.0059 | 0.00736 |
| 4.1 | 0.0728 | 0.002 | | 0.00494 | 0.0059 | 0.00736 |
| 4.2 | 0.0748 | 0.002 | | 0.00494 | 0.0059 | 0.00736 |
| 4.3 | 0.0768 | 0.002 | | 0.00494 | 0.0059 | 0.00736 |

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| 4.4 | 0.0788 | 0.002 | 0.00494 | 0.0059 | 0.00736 |
| 4.5 | 0.0809 | 0.0021 | 0.00494 | 0.0059 | 0.00736 |
| 4.6 | 0.0829 | 0.002 | 0.005187 | 0.006195 | 0.007728 |
| 4.7 | 0.085 | 0.0021 | 0.00494 | 0.0059 | 0.00736 |
| 4.8 | 0.087 | 0.002 | 0.005187 | 0.006195 | 0.007728 |
| 4.9 | 0.0891 | 0.0021 | 0.00494 | 0.0059 | 0.00736 |
| 5 | 0.0912 | 0.0021 | 0.005187 | 0.006195 | 0.007728 |
| 5.1 | 0.0933 | 0.0021 | 0.005187 | 0.006195 | 0.007728 |
| 5.2 | 0.0954 | 0.0021 | 0.005187 | 0.006195 | 0.007728 |
| 5.3 | 0.0976 | 0.0022 | 0.005187 | 0.006195 | 0.007728 |
| 5.4 | 0.0997 | 0.0021 | 0.005434 | 0.00649 | 0.008096 |
| 5.5 | 0.1019 | 0.0022 | 0.005187 | 0.006195 | 0.007728 |
| 5.6 | 0.104 | 0.0021 | 0.005434 | 0.00649 | 0.008096 |
| 5.7 | 0.1062 | 0.0022 | 0.005187 | 0.006195 | 0.007728 |
| 5.8 | 0.1084 | 0.0022 | 0.005434 | 0.00649 | 0.008096 |
| 5.9 | 0.1106 | 0.0022 | 0.005434 | 0.00649 | 0.008096 |
| 6 | 0.1128 | 0.0022 | 0.005434 | 0.00649 | 0.008096 |
| 6.1 | 0.1152 | 0.0024 | 0.005434 | 0.00649 | 0.008096 |
| 6.2 | 0.1176 | 0.0024 | 0.005928 | 0.00708 | 0.008832 |
| 6.3 | 0.1201 | 0.0025 | 0.005928 | 0.00708 | 0.008832 |
| 6.4 | 0.1226 | 0.0025 | 0.006175 | 0.007375 | 0.0092 |
| 6.5 | 0.1251 | 0.0025 | 0.006175 | 0.007375 | 0.0092 |
| 6.6 | 0.1277 | 0.0026 | 0.006175 | 0.007375 | 0.0092 |
| 6.7 | 0.1303 | 0.0026 | 0.006422 | 0.00767 | 0.009568 |
| 6.8 | 0.1329 | 0.0026 | 0.006422 | 0.00767 | 0.009568 |
| 6.9 | 0.1356 | 0.0027 | 0.006422 | 0.00767 | 0.009568 |
| 7 | 0.1383 | 0.0027 | 0.006669 | 0.007965 | 0.009936 |
| 7.1 | 0.1411 | 0.0028 | 0.006669 | 0.007965 | 0.009936 |
| 7.2 | 0.1438 | 0.0027 | 0.006916 | 0.00826 | 0.010304 |
| 7.3 | 0.1467 | 0.0029 | 0.006669 | 0.007965 | 0.009936 |
| 7.4 | 0.1495 | 0.0028 | 0.007163 | 0.008555 | 0.010672 |
| 7.5 | 0.1524 | 0.0029 | 0.006916 | 0.00826 | 0.010304 |
| 7.6 | 0.1553 | 0.0029 | 0.007163 | 0.008555 | 0.010672 |
| 7.7 | 0.1582 | 0.0029 | 0.007163 | 0.008555 | 0.010672 |
| 7.8 | 0.1611 | 0.0029 | 0.007163 | 0.008555 | 0.010672 |
| 7.9 | 0.1641 | 0.003 | 0.007163 | 0.008555 | 0.010672 |
| 8 | 0.1671 | 0.003 | 0.00741 | 0.00885 | 0.01104 |
| 8.1 | 0.1702 | 0.0031 | 0.00741 | 0.00885 | 0.01104 |
| 8.2 | 0.1733 | 0.0031 | 0.007657 | 0.009145 | 0.011408 |
| 8.3 | 0.1764 | 0.0031 | 0.007657 | 0.009145 | 0.011408 |
| 8.4 | 0.1796 | 0.0032 | 0.007657 | 0.009145 | 0.011408 |
| 8.5 | 0.1828 | 0.0032 | 0.007904 | 0.00944 | 0.011776 |
| 8.6 | 0.186 | 0.0032 | 0.007904 | 0.00944 | 0.011776 |
| 8.7 | 0.1893 | 0.0033 | 0.007904 | 0.00944 | 0.011776 |
| 8.8 | 0.1925 | 0.0032 | 0.008151 | 0.009735 | 0.012144 |

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| 8.9 | 0.1959 | 0.0034 | 0.007904 | 0.00944 | 0.011776 |
| 9 | 0.1992 | 0.0033 | 0.008398 | 0.01003 | 0.012512 |
| 9.1 | 0.2027 | 0.0035 | 0.008151 | 0.009735 | 0.012144 |
| 9.2 | 0.2063 | 0.0036 | 0.008645 | 0.010325 | 0.01288 |
| 9.3 | 0.21 | 0.0037 | 0.008892 | 0.01062 | 0.013248 |
| 9.4 | 0.2139 | 0.0039 | 0.009139 | 0.010915 | 0.013616 |
| 9.5 | 0.2179 | 0.004 | 0.009633 | 0.011505 | 0.014352 |
| 9.6 | 0.222 | 0.0041 | 0.00988 | 0.0118 | 0.01472 |
| 9.7 | 0.2263 | 0.0043 | 0.010127 | 0.012095 | 0.015088 |
| 9.8 | 0.2307 | 0.0044 | 0.010621 | 0.012685 | 0.015824 |
| 9.9 | 0.2352 | 0.0045 | 0.010868 | 0.01298 | 0.016192 |
| 10 | 0.2398 | 0.0046 | 0.011115 | 0.013275 | 0.01656 |
| 10.1 | 0.2446 | 0.0048 | 0.011362 | 0.01357 | 0.016928 |
| 10.2 | 0.2495 | 0.0049 | 0.011856 | 0.01416 | 0.017664 |
| 10.3 | 0.2546 | 0.0051 | 0.012103 | 0.014455 | 0.018032 |
| 10.4 | 0.2597 | 0.0051 | 0.012597 | 0.015045 | 0.018768 |
| 10.5 | 0.265 | 0.0053 | 0.012597 | 0.015045 | 0.018768 |
| 10.6 | 0.2708 | 0.0058 | 0.013091 | 0.015635 | 0.019504 |
| 10.7 | 0.2769 | 0.0061 | 0.014326 | 0.01711 | 0.021344 |
| 10.8 | 0.2833 | 0.0064 | 0.015067 | 0.017995 | 0.022448 |
| 10.9 | 0.29 | 0.0067 | 0.015808 | 0.01888 | 0.023552 |
| 11 | 0.297 | 0.007 | 0.016549 | 0.019765 | 0.024656 |
| 11.1 | 0.3048 | 0.0078 | 0.01729 | 0.02065 | 0.02576 |
| 11.2 | 0.313 | 0.0082 | 0.019266 | 0.02301 | 0.028704 |
| 11.3 | 0.3216 | 0.0086 | 0.020254 | 0.02419 | 0.030176 |
| 11.4 | 0.3307 | 0.0091 | 0.021242 | 0.02537 | 0.031648 |
| 11.5 | 0.3402 | 0.0095 | 0.022477 | 0.026845 | 0.033488 |
| 11.6 | 0.3524 | 0.0122 | 0.023465 | 0.028025 | 0.03496 |
| 11.7 | 0.3652 | 0.0128 | 0.030134 | 0.03599 | 0.044896 |
| 11.8 | 0.3842 | 0.019 | 0.031616 | 0.03776 | 0.047104 |
| 11.9 | 0.4135 | 0.0293 | 0.04693 | 0.05605 | 0.06992 |
| 12 | 0.4737 | 0.0602 | 0.072371 | 0.086435 | 0.107824 |
| 12.1 | 0.5865 | 0.1128 | 0.148694 | 0.17759 | 0.221536 |
| 12.2 | 0.6158 | 0.0293 | 0.278616 | 0.33276 | 0.415104 |
| 12.3 | 0.6348 | 0.019 | 0.072371 | 0.086435 | 0.107824 |
| 12.4 | 0.6476 | 0.0128 | 0.04693 | 0.05605 | 0.06992 |
| 12.5 | 0.6598 | 0.0122 | 0.031616 | 0.03776 | 0.047104 |
| 12.6 | 0.6693 | 0.0095 | 0.030134 | 0.03599 | 0.044896 |
| 12.7 | 0.6784 | 0.0091 | 0.023465 | 0.028025 | 0.03496 |
| 12.8 | 0.687 | 0.0086 | 0.022477 | 0.026845 | 0.033488 |
| 12.9 | 0.6952 | 0.0082 | 0.021242 | 0.02537 | 0.031648 |
| 13 | 0.703 | 0.0078 | 0.020254 | 0.02419 | 0.030176 |
| 13.1 | 0.71 | 0.007 | 0.019266 | 0.02301 | 0.028704 |
| 13.2 | 0.7167 | 0.0067 | 0.01729 | 0.02065 | 0.02576 |
| 13.3 | 0.7231 | 0.0064 | 0.016549 | 0.019765 | 0.024656 |

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| 13.4 | 0.7292 | 0.0061 | 0.015808 | 0.01888 | 0.023552 |
| 13.5 | 0.735 | 0.0058 | 0.015067 | 0.017995 | 0.022448 |
| 13.6 | 0.7403 | 0.0053 | 0.014326 | 0.01711 | 0.021344 |
| 13.7 | 0.7454 | 0.0051 | 0.013091 | 0.015635 | 0.019504 |
| 13.8 | 0.7505 | 0.0051 | 0.012597 | 0.015045 | 0.018768 |
| 13.9 | 0.7554 | 0.0049 | 0.012597 | 0.015045 | 0.018768 |
| 14 | 0.7602 | 0.0048 | 0.012103 | 0.014455 | 0.018032 |
| 14.1 | 0.7648 | 0.0046 | 0.011856 | 0.01416 | 0.017664 |
| 14.2 | 0.7693 | 0.0045 | 0.011362 | 0.01357 | 0.016928 |
| 14.3 | 0.7737 | 0.0044 | 0.011115 | 0.013275 | 0.01656 |
| 14.4 | 0.778 | 0.0043 | 0.010868 | 0.01298 | 0.016192 |
| 14.5 | 0.7821 | 0.0041 | 0.010621 | 0.012685 | 0.015824 |
| 14.6 | 0.7861 | 0.004 | 0.010127 | 0.012095 | 0.015088 |
| 14.7 | 0.79 | 0.0039 | 0.00988 | 0.0118 | 0.01472 |
| 14.8 | 0.7937 | 0.0037 | 0.009633 | 0.011505 | 0.014352 |
| 14.9 | 0.7973 | 0.0036 | 0.009139 | 0.010915 | 0.013616 |
| 15 | 0.8008 | 0.0035 | 0.008892 | 0.01062 | 0.013248 |
| 15.1 | 0.8041 | 0.0033 | 0.008645 | 0.010325 | 0.01288 |
| 15.2 | 0.8075 | 0.0034 | 0.008151 | 0.009735 | 0.012144 |
| 15.3 | 0.8107 | 0.0032 | 0.008398 | 0.01003 | 0.012512 |
| 15.4 | 0.814 | 0.0033 | 0.007904 | 0.00944 | 0.011776 |
| 15.5 | 0.8172 | 0.0032 | 0.008151 | 0.009735 | 0.012144 |
| 15.6 | 0.8204 | 0.0032 | 0.007904 | 0.00944 | 0.011776 |
| 15.7 | 0.8236 | 0.0032 | 0.007904 | 0.00944 | 0.011776 |
| 15.8 | 0.8267 | 0.0031 | 0.007904 | 0.00944 | 0.011776 |
| 15.9 | 0.8298 | 0.0031 | 0.007657 | 0.009145 | 0.011408 |
| 16 | 0.8329 | 0.0031 | 0.007657 | 0.009145 | 0.011408 |
| 16.1 | 0.8359 | 0.003 | 0.007657 | 0.009145 | 0.011408 |
| 16.2 | 0.8389 | 0.003 | 0.00741 | 0.00885 | 0.01104 |
| 16.3 | 0.8418 | 0.0029 | 0.00741 | 0.00885 | 0.01104 |
| 16.4 | 0.8447 | 0.0029 | 0.007163 | 0.008555 | 0.010672 |
| 16.5 | 0.8476 | 0.0029 | 0.007163 | 0.008555 | 0.010672 |
| 16.6 | 0.8505 | 0.0029 | 0.007163 | 0.008555 | 0.010672 |
| 16.7 | 0.8533 | 0.0028 | 0.007163 | 0.008555 | 0.010672 |
| 16.8 | 0.8562 | 0.0029 | 0.006916 | 0.00826 | 0.010304 |
| 16.9 | 0.8589 | 0.0027 | 0.007163 | 0.008555 | 0.010672 |
| 17 | 0.8617 | 0.0028 | 0.006669 | 0.007965 | 0.009936 |
| 17.1 | 0.8644 | 0.0027 | 0.006916 | 0.00826 | 0.010304 |
| 17.2 | 0.8671 | 0.0027 | 0.006669 | 0.007965 | 0.009936 |
| 17.3 | 0.8697 | 0.0026 | 0.006669 | 0.007965 | 0.009936 |
| 17.4 | 0.8723 | 0.0026 | 0.006422 | 0.00767 | 0.009568 |
| 17.5 | 0.8749 | 0.0026 | 0.006422 | 0.00767 | 0.009568 |
| 17.6 | 0.8774 | 0.0025 | 0.006422 | 0.00767 | 0.009568 |
| 17.7 | 0.8799 | 0.0025 | 0.006175 | 0.007375 | 0.0092 |
| 17.8 | 0.8824 | 0.0025 | 0.006175 | 0.007375 | 0.0092 |

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|---|---|---|---|---|---|
| 17.9 | 0.8848 | 0.0024 | 0.006175 | 0.007375 | 0.0092 |
| 18 | 0.8872 | 0.0024 | 0.005928 | 0.00708 | 0.008832 |
| 18.1 | 0.8894 | 0.0022 | 0.005928 | 0.00708 | 0.008832 |
| 18.2 | 0.8916 | 0.0022 | 0.005434 | 0.00649 | 0.008096 |
| 18.3 | 0.8938 | 0.0022 | 0.005434 | 0.00649 | 0.008096 |
| 18.4 | 0.896 | 0.0022 | 0.005434 | 0.00649 | 0.008096 |
| 18.5 | 0.8981 | 0.0021 | 0.005434 | 0.00649 | 0.008096 |
| 18.6 | 0.9003 | 0.0022 | 0.005187 | 0.006195 | 0.007728 |
| 18.7 | 0.9024 | 0.0021 | 0.005434 | 0.00649 | 0.008096 |
| 18.8 | 0.9046 | 0.0022 | 0.005187 | 0.006195 | 0.007728 |
| 18.9 | 0.9067 | 0.0021 | 0.005434 | 0.00649 | 0.008096 |
| 19 | 0.9088 | 0.0021 | 0.005187 | 0.006195 | 0.007728 |
| 19.1 | 0.9109 | 0.0021 | 0.005187 | 0.006195 | 0.007728 |
| 19.2 | 0.913 | 0.0021 | 0.005187 | 0.006195 | 0.007728 |
| 19.3 | 0.915 | 0.002 | 0.005187 | 0.006195 | 0.007728 |
| 19.4 | 0.9171 | 0.0021 | 0.00494 | 0.0059 | 0.00736 |
| 19.5 | 0.9191 | 0.002 | 0.005187 | 0.006195 | 0.007728 |
| 19.6 | 0.9212 | 0.0021 | 0.00494 | 0.0059 | 0.00736 |
| 19.7 | 0.9232 | 0.002 | 0.005187 | 0.006195 | 0.007728 |
| 19.8 | 0.9252 | 0.002 | 0.00494 | 0.0059 | 0.00736 |
| 19.9 | 0.9272 | 0.002 | 0.00494 | 0.0059 | 0.00736 |
| 20 | 0.9292 | 0.002 | 0.00494 | 0.0059 | 0.00736 |
| 20.1 | 0.9312 | 0.002 | 0.00494 | 0.0059 | 0.00736 |
| 20.2 | 0.9332 | 0.002 | 0.00494 | 0.0059 | 0.00736 |
| 20.3 | 0.9351 | 0.0019 | 0.00494 | 0.0059 | 0.00736 |
| 20.4 | 0.9371 | 0.002 | 0.004693 | 0.005605 | 0.006992 |
| 20.5 | 0.939 | 0.0019 | 0.00494 | 0.0059 | 0.00736 |
| 20.6 | 0.9409 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 20.7 | 0.9428 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 20.8 | 0.9447 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 20.9 | 0.9466 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 21 | 0.9485 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 21.1 | 0.9504 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 21.2 | 0.9523 | 0.0019 | 0.004693 | 0.005605 | 0.006992 |
| 21.3 | 0.9541 | 0.0018 | 0.004693 | 0.005605 | 0.006992 |
| 21.4 | 0.956 | 0.0019 | 0.004446 | 0.00531 | 0.006624 |
| 21.5 | 0.9578 | 0.0018 | 0.004693 | 0.005605 | 0.006992 |
| 21.6 | 0.9596 | 0.0018 | 0.004446 | 0.00531 | 0.006624 |
| 21.7 | 0.9614 | 0.0018 | 0.004446 | 0.00531 | 0.006624 |
| 21.8 | 0.9632 | 0.0018 | 0.004446 | 0.00531 | 0.006624 |
| 21.9 | 0.965 | 0.0018 | 0.004446 | 0.00531 | 0.006624 |
| 22 | 0.9668 | 0.0018 | 0.004446 | 0.00531 | 0.006624 |
| 22.1 | 0.9686 | 0.0018 | 0.004446 | 0.00531 | 0.006624 |
| 22.2 | 0.9703 | 0.0017 | 0.004446 | 0.00531 | 0.006624 |
| 22.3 | 0.9721 | 0.0018 | 0.004199 | 0.005015 | 0.006256 |

| | | | | | |
|---|---|---|---|---|---|
| 22.4 | 0.9738 | 0.0017 | 0.004446 | 0.00531 | 0.006624 |
| 22.5 | 0.9755 | 0.0017 | 0.004199 | 0.005015 | 0.006256 |
| 22.6 | 0.9772 | 0.0017 | 0.004199 | 0.005015 | 0.006256 |
| 22.7 | 0.9789 | 0.0017 | 0.004199 | 0.005015 | 0.006256 |
| 22.8 | 0.9806 | 0.0017 | 0.004199 | 0.005015 | 0.006256 |
| 22.9 | 0.9823 | 0.0017 | 0.004199 | 0.005015 | 0.006256 |
| 23 | 0.984 | 0.0017 | 0.004199 | 0.005015 | 0.006256 |
| 23.1 | 0.9856 | 0.0016 | 0.004199 | 0.005015 | 0.006256 |
| 23.2 | 0.9873 | 0.0017 | 0.003952 | 0.00472 | 0.005888 |
| 23.3 | 0.9889 | 0.0016 | 0.004199 | 0.005015 | 0.006256 |
| 23.4 | 0.9905 | 0.0016 | 0.003952 | 0.00472 | 0.005888 |
| 23.5 | 0.9921 | 0.0016 | 0.003952 | 0.00472 | 0.005888 |
| 23.6 | 0.9937 | 0.0016 | 0.003952 | 0.00472 | 0.005888 |
| 23.7 | 0.9953 | 0.0016 | 0.003952 | 0.00472 | 0.005888 |
| 23.8 | 0.9969 | 0.0016 | 0.003952 | 0.00472 | 0.005888 |
| 23.9 | 0.9984 | 0.0015 | 0.003952 | 0.00472 | 0.005888 |
| 24 | 1 | 0.0016 | 0.003705 | 0.004425 | 0.00552 |
| | | | 0.003952 | 0.00472 | 0.005888 |
| | | | 2.47 | | |

| 10 | 25 | 50 | 100 | | | |
|---|---|---|---|---|---|---|
| 4.35 | 5.43 | 6.42 | 7.6 | Soil Infilt | Top Infilt | |
| 0 | 0 | 0 | 0 | 0.04 | 0.1 | |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | |
| 0.006525 | 0.008145 | 0.00963 | 0.0114 | 0.04 | 0.1 | |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | 0.4 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | 1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 | |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 | |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 | |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 | |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 | |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 | |

| | | | | | |
|---|---|---|---|---|---|
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.01044 | 0.013032 | 0.015408 | 0.01824 | 0.04 | 0.1 |
| 0.01044 | 0.013032 | 0.015408 | 0.01824 | 0.04 | 0.1 |
| 0.010875 | 0.013575 | 0.01605 | 0.019 | 0.04 | 0.1 |
| 0.010875 | 0.013575 | 0.01605 | 0.019 | 0.04 | 0.1 |
| 0.010875 | 0.013575 | 0.01605 | 0.019 | 0.04 | 0.1 |
| 0.01131 | 0.014118 | 0.016692 | 0.01976 | 0.04 | 0.1 |
| 0.01131 | 0.014118 | 0.016692 | 0.01976 | 0.04 | 0.1 |
| 0.01131 | 0.014118 | 0.016692 | 0.01976 | 0.04 | 0.1 |
| 0.011745 | 0.014661 | 0.017334 | 0.02052 | 0.04 | 0.1 |
| 0.011745 | 0.014661 | 0.017334 | 0.02052 | 0.04 | 0.1 |
| 0.01218 | 0.015204 | 0.017976 | 0.02128 | 0.04 | 0.1 |
| 0.011745 | 0.014661 | 0.017334 | 0.02052 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.01218 | 0.015204 | 0.017976 | 0.02128 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.01305 | 0.01629 | 0.01926 | 0.0228 | 0.04 | 0.1 |
| 0.01305 | 0.01629 | 0.01926 | 0.0228 | 0.04 | 0.1 |
| 0.013485 | 0.016833 | 0.019902 | 0.02356 | 0.04 | 0.1 |
| 0.013485 | 0.016833 | 0.019902 | 0.02356 | 0.04 | 0.1 |
| 0.013485 | 0.016833 | 0.019902 | 0.02356 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.014355 | 0.017919 | 0.021186 | 0.02508 | 0.04 | 0.1 |

| | | | | | |
|---|---|---|---|---|---|
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.01479 | 0.018462 | 0.021828 | 0.02584 | 0.04 | 0.1 |
| 0.014355 | 0.017919 | 0.021186 | 0.02508 | 0.04 | 0.1 |
| 0.015225 | 0.019005 | 0.02247 | 0.0266 | 0.04 | 0.1 |
| 0.01566 | 0.019548 | 0.023112 | 0.02736 | 0.04 | 0.1 |
| 0.016095 | 0.020091 | 0.023754 | 0.02812 | 0.04 | 0.1 |
| 0.016965 | 0.021177 | 0.025038 | 0.02964 | 0.04 | 0.1 |
| 0.0174 | 0.02172 | 0.02568 | 0.0304 | 0.04 | 0.1 |
| 0.017835 | 0.022263 | 0.026322 | 0.03116 | 0.04 | 0.1 |
| 0.018705 | 0.023349 | 0.027606 | 0.03268 | 0.04 | 0.1 |
| 0.01914 | 0.023892 | 0.028248 | 0.03344 | 0.04 | 0.1 |
| 0.019575 | 0.024435 | 0.02889 | 0.0342 | 0.04 | 0.1 |
| 0.02001 | 0.024978 | 0.029532 | 0.03496 | 0.04 | 0.1 |
| 0.02088 | 0.026064 | 0.030816 | 0.03648 | 0.04 | 0.1 |
| 0.021315 | 0.026607 | 0.031458 | 0.03724 | 0.04 | 0.1 |
| 0.022185 | 0.027693 | 0.032742 | 0.03876 | 0.04 | 0.1 |
| 0.022185 | 0.027693 | 0.032742 | 0.03876 | 0.04 | 0.1 |
| 0.023055 | 0.028779 | 0.034026 | 0.04028 | 0.04 | 0.1 |
| 0.02523 | 0.031494 | 0.037236 | 0.04408 | 0.04 | 0.1 |
| 0.026535 | 0.033123 | 0.039162 | 0.04636 | 0.04 | 0.1 |
| 0.02784 | 0.034752 | 0.041088 | 0.04864 | 0.04 | 0.1 |
| 0.029145 | 0.036381 | 0.043014 | 0.05092 | 0.04 | 0.1 |
| 0.03045 | 0.03801 | 0.04494 | 0.0532 | 0.04 | 0.1 |
| 0.03393 | 0.042354 | 0.050076 | 0.05928 | 0.04 | 0.1 |
| 0.03567 | 0.044526 | 0.052644 | 0.06232 | 0.04 | 0.1 |
| 0.03741 | 0.046698 | 0.055212 | 0.06536 | 0.04 | 0.1 |
| 0.039585 | 0.049413 | 0.058422 | 0.06916 | 0.04 | 0.1 |
| 0.041325 | 0.051585 | 0.06099 | 0.0722 | 0.04 | 0.1 |
| 0.05307 | 0.066246 | 0.078324 | 0.09272 | 0.04 | 0.1 |
| 0.05568 | 0.069504 | 0.082176 | 0.09728 | 0.04 | 0.1 |
| 0.08265 | 0.10317 | 0.12198 | 0.1444 | 0.04 | 0.1 |
| 0.127455 | 0.159099 | 0.188106 | 0.22268 | 0.04 | 0.1 |
| 0.26187 | 0.326886 | 0.386484 | 0.45752 | 0.04 | 0.1 |
| 0.49068 | 0.612504 | 0.724176 | 0.85728 | 0.04 | 0.1 |
| 0.127455 | 0.159099 | 0.188106 | 0.22268 | 0.04 | 0.1 |
| 0.08265 | 0.10317 | 0.12198 | 0.1444 | 0.04 | 0.1 |
| 0.05568 | 0.069504 | 0.082176 | 0.09728 | 0.04 | 0.1 |
| 0.05307 | 0.066246 | 0.078324 | 0.09272 | 0.04 | 0.1 |
| 0.041325 | 0.051585 | 0.06099 | 0.0722 | 0.04 | 0.1 |
| 0.039585 | 0.049413 | 0.058422 | 0.06916 | 0.04 | 0.1 |
| 0.03741 | 0.046698 | 0.055212 | 0.06536 | 0.04 | 0.1 |
| 0.03567 | 0.044526 | 0.052644 | 0.06232 | 0.04 | 0.1 |
| 0.03393 | 0.042354 | 0.050076 | 0.05928 | 0.04 | 0.1 |
| 0.03045 | 0.03801 | 0.04494 | 0.0532 | 0.04 | 0.1 |
| 0.029145 | 0.036381 | 0.043014 | 0.05092 | 0.04 | 0.1 |

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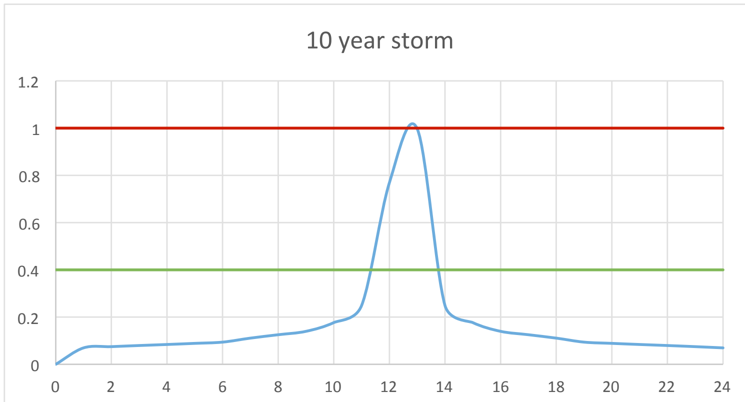
|---|---|---|---|---|---|
| 0.02784 | 0.034752 | 0.041088 | 0.04864 | 0.04 | 0.1 |
| 0.026535 | 0.033123 | 0.039162 | 0.04636 | 0.04 | 0.1 |
| 0.02523 | 0.031494 | 0.037236 | 0.04408 | 0.04 | 0.1 |
| 0.023055 | 0.028779 | 0.034026 | 0.04028 | 0.04 | 0.1 |
| 0.022185 | 0.027693 | 0.032742 | 0.03876 | 0.04 | 0.1 |
| 0.022185 | 0.027693 | 0.032742 | 0.03876 | 0.04 | 0.1 |
| 0.021315 | 0.026607 | 0.031458 | 0.03724 | 0.04 | 0.1 |
| 0.02088 | 0.026064 | 0.030816 | 0.03648 | 0.04 | 0.1 |
| 0.02001 | 0.024978 | 0.029532 | 0.03496 | 0.04 | 0.1 |
| 0.019575 | 0.024435 | 0.02889 | 0.0342 | 0.04 | 0.1 |
| 0.01914 | 0.023892 | 0.028248 | 0.03344 | 0.04 | 0.1 |
| 0.018705 | 0.023349 | 0.027606 | 0.03268 | 0.04 | 0.1 |
| 0.017835 | 0.022263 | 0.026322 | 0.03116 | 0.04 | 0.1 |
| 0.0174 | 0.02172 | 0.02568 | 0.0304 | 0.04 | 0.1 |
| 0.016965 | 0.021177 | 0.025038 | 0.02964 | 0.04 | 0.1 |
| 0.016095 | 0.020091 | 0.023754 | 0.02812 | 0.04 | 0.1 |
| 0.01566 | 0.019548 | 0.023112 | 0.02736 | 0.04 | 0.1 |
| 0.015225 | 0.019005 | 0.02247 | 0.0266 | 0.04 | 0.1 |
| 0.014355 | 0.017919 | 0.021186 | 0.02508 | 0.04 | 0.1 |
| 0.01479 | 0.018462 | 0.021828 | 0.02584 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.014355 | 0.017919 | 0.021186 | 0.02508 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.01392 | 0.017376 | 0.020544 | 0.02432 | 0.04 | 0.1 |
| 0.013485 | 0.016833 | 0.019902 | 0.02356 | 0.04 | 0.1 |
| 0.013485 | 0.016833 | 0.019902 | 0.02356 | 0.04 | 0.1 |
| 0.013485 | 0.016833 | 0.019902 | 0.02356 | 0.04 | 0.1 |
| 0.01305 | 0.01629 | 0.01926 | 0.0228 | 0.04 | 0.1 |
| 0.01305 | 0.01629 | 0.01926 | 0.0228 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.01218 | 0.015204 | 0.017976 | 0.02128 | 0.04 | 0.1 |
| 0.012615 | 0.015747 | 0.018618 | 0.02204 | 0.04 | 0.1 |
| 0.011745 | 0.014661 | 0.017334 | 0.02052 | 0.04 | 0.1 |
| 0.01218 | 0.015204 | 0.017976 | 0.02128 | 0.04 | 0.1 |
| 0.011745 | 0.014661 | 0.017334 | 0.02052 | 0.04 | 0.1 |
| 0.011745 | 0.014661 | 0.017334 | 0.02052 | 0.04 | 0.1 |
| 0.01131 | 0.014118 | 0.016692 | 0.01976 | 0.04 | 0.1 |
| 0.01131 | 0.014118 | 0.016692 | 0.01976 | 0.04 | 0.1 |
| 0.01131 | 0.014118 | 0.016692 | 0.01976 | 0.04 | 0.1 |
| 0.010875 | 0.013575 | 0.01605 | 0.019 | 0.04 | 0.1 |
| 0.010875 | 0.013575 | 0.01605 | 0.019 | 0.04 | 0.1 |

| | | | | | |
|---|---|---|---|---|---|
| 0.010875 | 0.013575 | 0.01605 | 0.019 | 0.04 | 0.1 |
| 0.01044 | 0.013032 | 0.015408 | 0.01824 | 0.04 | 0.1 |
| 0.01044 | 0.013032 | 0.015408 | 0.01824 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.00957 | 0.011946 | 0.014124 | 0.01672 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.009135 | 0.011403 | 0.013482 | 0.01596 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.0087 | 0.01086 | 0.01284 | 0.0152 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.008265 | 0.010317 | 0.012198 | 0.01444 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |

| | | | | | |
|---|---|---|---|---|---|
| 0.00783 | 0.009774 | 0.011556 | 0.01368 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.007395 | 0.009231 | 0.010914 | 0.01292 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |
| 0.006525 | 0.008145 | 0.00963 | 0.0114 | 0.04 | 0.1 |
| 0.00696 | 0.008688 | 0.010272 | 0.01216 | 0.04 | 0.1 |




| yr strm | 1 | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| depth rainfall | 2.47 | 2.95 | 3.68 | 4.35 | 5.43 | 6.42 | 7.6 |
| infiltrated | 2.24269 | 2.63965 | 3.227712 | 3.74254 | 4.566072 | 5.289168 | 6.15104 |
| stored water | 0.198602 | 0.24497 | 0.32384 | 0.38545 | 0.540652 | 0.693772 | 0.9236 |
| Runoff Depth | 0.22731 | 0.31035 | 0.452288 | 0.60746 | 0.863928 | 1.130832 | 1.44896 |
| | | | | | | | |
| | 2.24 | 2.64 | 3.23 | 3.74 | 4.57 | 5.29 | 6.15 |

| Time | 10 yr storm | |
|---|---|---|
| 0 | 0 | 0 |
| | 0.00696 | |
| | 0.006525 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.007395 | |
| 1 | 0.00696 | 0.0696 |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.00783 | |
| | 0.007395 | |
| 2 | 0.00783 | 0.07482 |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.008265 | |
| | 0.00783 | |
| | 0.008265 | |
| 3 | 0.008265 | 0.079605 |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.0087 | |
| | 0.008265 | |
| | 0.0087 | |
| 4 | 0.0087 | 0.083955 |
| | 0.0087 | |
| | 0.0087 | |

| | | | |
|---|---|---|---|
| 0 | 0 | 0.4 | 1 |
| 1 | 0.0696 | 0.4 | 1 |
| 2 | 0.07482 | 0.4 | 1 |
| 3 | 0.079605 | 0.4 | 1 |
| 4 | 0.083955 | 0.4 | 1 |
| 5 | 0.08874 | 0.4 | 1 |
| 6 | 0.09396 | 0.4 | 1 |
| 7 | 0.1109025 | 0.4 | 1 |
| 8 | 0.12528 | 0.4 | 1 |
| 9 | 0.139635 | 0.4 | 1 |
| 10 | 0.17661 | 0.4 | 1 |
| 11 | 0.24882 | 0.4 | 1 |
| 12 | 0.768645 | 0.4 | 1 |
| 13 | 0.997455 | 0.4 | 1 |
| 14 | 0.24882 | 0.4 | 1 |
| 15 | 0.17661 | 0.4 | 1 |
| 16 | 0.139635 | 0.4 | 1 |
| 17 | 0.12528 | 0.4 | 1 |
| 18 | 0.110925 | 0.4 | 1 |
| 19 | 0.09396 | 0.4 | 1 |
| 20 | 0.08874 | 0.4 | 1 |
| 21 | 0.083955 | 0.4 | 1 |
| 22 | 0.079605 | 0.4 | 1 |
| 23 | 0.07482 | 0.4 | 1 |
| 24 | 0.0696 | 0.4 | 1 |
| | 4.3499775 | | |

| | | |
|---|---|---|
| | 0.0087 | |
| | 0.0087 | |
| | 0.009135 | |
| | 0.0087 | |
| | 0.009135 | |
| | 0.0087 | |
| | 0.009135 | |
| 5 | 0.009135 | 0.08874 |
| | 0.009135 | |
| | 0.009135 | |
| | 0.00957 | |
| | 0.009135 | |
| | 0.00957 | |
| | 0.009135 | |
| | 0.00957 | |
| | 0.00957 | |
| | 0.00957 | |
| 6 | 0.00957 | 0.09396 |
| | 0.01044 | |
| | 0.01044 | |
| | 0.010875 | |
| | 0.010875 | |
| | 0.010875 | |
| | 0.01131 | |
| | 0.01131 | |
| | 0.01131 | |
| | 0.011745 | |
| 7 | 0.011745 | 0.110925 |
| | 0.01218 | |
| | 0.011745 | |
| | 0.012615 | |
| | 0.01218 | |
| | 0.012615 | |
| | 0.012615 | |
| | 0.012615 | |
| | 0.012615 | |
| | 0.01305 | |
| 8 | 0.01305 | 0.12528 |
| | 0.013485 | |
| | 0.013485 | |
| | 0.013485 | |
| | 0.01392 | |
| | 0.01392 | |
| | 0.01392 | |
| | 0.014355 | |

| | | |
|---|---|---|
| | 0.01392 | |
| | 0.01479 | |
| 9 | 0.014355 | 0.139635 |
| | 0.015225 | |
| | 0.01566 | |
| | 0.016095 | |
| | 0.016965 | |
| | 0.0174 | |
| | 0.017835 | |
| | 0.018705 | |
| | 0.01914 | |
| | 0.019575 | |
| 10 | 0.02001 | 0.17661 |
| | 0.02088 | |
| | 0.021315 | |
| | 0.022185 | |
| | 0.022185 | |
| | 0.023055 | |
| | 0.02523 | |
| | 0.026535 | |
| | 0.02784 | |
| | 0.029145 | |
| 11 | 0.03045 | 0.24882 |
| | 0.03393 | |
| | 0.03567 | |
| | 0.03741 | |
| | 0.039585 | |
| | 0.041325 | |
| | 0.05307 | |
| | 0.05568 | |
| | 0.08265 | |
| | 0.127455 | |
| 12 | 0.26187 | 0.768645 |
| | 0.49068 | |
| | 0.127455 | |
| | 0.08265 | |
| | 0.05568 | |
| | 0.05307 | |
| | 0.041325 | |
| | 0.039585 | |
| | 0.03741 | |
| | 0.03567 | |
| 13 | 0.03393 | 0.997455 |
| | 0.03045 | |
| | 0.029145 | |

| | | |
|---|---|---|
| | 0.02784 | |
| | 0.026535 | |
| | 0.02523 | |
| | 0.023055 | |
| | 0.022185 | |
| | 0.022185 | |
| | 0.021315 | |
| 14 | 0.02088 | 0.24882 |
| | 0.02001 | |
| | 0.019575 | |
| | 0.01914 | |
| | 0.018705 | |
| | 0.017835 | |
| | 0.0174 | |
| | 0.016965 | |
| | 0.016095 | |
| | 0.01566 | |
| 15 | 0.015225 | 0.17661 |
| | 0.014355 | |
| | 0.01479 | |
| | 0.01392 | |
| | 0.014355 | |
| | 0.01392 | |
| | 0.01392 | |
| | 0.01392 | |
| | 0.013485 | |
| | 0.013485 | |
| 16 | 0.013485 | 0.139635 |
| | 0.01305 | |
| | 0.01305 | |
| | 0.012615 | |
| | 0.012615 | |
| | 0.012615 | |
| | 0.012615 | |
| | 0.01218 | |
| | 0.012615 | |
| | 0.011745 | |
| 17 | 0.01218 | 0.12528 |
| | 0.011745 | |
| | 0.011745 | |
| | 0.01131 | |
| | 0.01131 | |
| | 0.01131 | |
| | 0.010875 | |
| | 0.010875 | |

| | | |
|---|---|---|
| | 0.010875 | |
| | 0.01044 | |
| 18 | 0.01044 | 0.110925 |
| | 0.00957 | |
| | 0.00957 | |
| | 0.00957 | |
| | 0.00957 | |
| | 0.009135 | |
| | 0.00957 | |
| | 0.009135 | |
| | 0.00957 | |
| | 0.009135 | |
| 19 | 0.009135 | 0.09396 |
| | 0.009135 | |
| | 0.009135 | |
| | 0.0087 | |
| | 0.009135 | |
| | 0.0087 | |
| | 0.009135 | |
| | 0.0087 | |
| | 0.0087 | |
| | 0.0087 | |
| 20 | 0.0087 | 0.08874 |
| | 0.0087 | |
| | 0.0087 | |
| | 0.008265 | |
| | 0.0087 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| | 0.008265 | |
| 21 | 0.008265 | 0.083955 |
| | 0.008265 | |
| | 0.008265 | |
| | 0.00783 | |
| | 0.008265 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| | 0.00783 | |
| 22 | 0.00783 | 0.079605 |
| | 0.00783 | |
| | 0.007395 | |

| | | |
|---|---|---|
| | 0.00783 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| | 0.007395 | |
| 23 | 0.007395 | 0.07482 |
| | 0.00696 | |
| | 0.007395 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.00696 | |
| | 0.006525 | |
| 24 | 0.00696 | 0.0696 |
| | 4.35 | 4.35 |

Workbook 4:

| yr storm | | runoff (ft) | runoff (ft^3) |
|---|---|---|---|
| 1 | 1.22 | 0.1016667 | 68643.3 |
| 2 | 1.63 | 0.1358333 | 91711.95 |
| 5 | 2.26 | 0.1883333 | 127158.9 |
| 10 | 2.87 | 0.2391667 | 161480.55 |
| 25 | 3.88 | 0.3233333 | 218308.2 |
| 50 | 4.82 | 0.4016667 | 271197.3 |
| 100 | 5.95 | 0.4958333 | 334776.75 |

Q=(P-Ia)^2/((P-Ia)+1.62)

Q/12

Q/12*A R-pp

Vr

3.74

| | | |
|---|---|---|
| A | 15.5 ac | 43560 |
| ft^2 | 675180 | |
| | | |
| A2 | 1.5 ac | |
| | 67518 | |

| INFILTRATED | in -> ft | V removed |
|---|---|---|
| 2.24 | 0.186666667 | 12267.36 |
| 2.64 | 0.22 | 14457.96 |
| 3.23 | 0.269166667 | 17689.095 |
| 3.74 | 0.311666667 | 20482.11 |
| 4.57 | 0.380833333 | 25027.605 |
| 5.29 | 0.440833333 | 28970.685 |
| 6.15 | 0.5125 | 33680.475 |
| | | |
| | | Vi |

| yr storm | final runoff | percent reduction |
|---|---|---|
| 1 | 56375.94 | 17.87% |
| 2 | 77253.99 | 15.76% |
| 5 | 109469.805 | 13.91% |
| 10 | 140998.44 | 12.68% |
| 25 | 193280.595 | 11.46% |
| 50 | 242226.615 | 10.68% |
| 100 | 301096.275 | 10.06% |
| | | |
| | Runoff - infiltrated | |
| | | (R-inf)/R |